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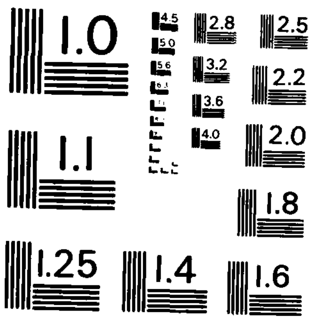

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REPORT

MRL-R-903

THE NICROSIL VERSUS NISIL TYPE N THERMOCOUPLE: A COMMERCIAL REALITY

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ABSTRACT

The Technology Transfer Council, Australia, through its Metals Technology Centre, has conducted a series of seminars on the nicrosil versus nisil thermocouple system in capital cities throughout Australia. These seminars, which culminated in the latter half of 1982, were directed towards the adoption of the new thermocouple in science and industry in Australia. The authors of this report presented papers at the seminars on various aspects of the formulation, development, standardization, laboratory and industrial testing, and the commercial adaption and utilization of the nicrosil versus nisil system. This report, which is a consolidated summary of their presentations, constitutes the Proceedings of the seminars.

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ABSTRACT

The Technology Transfer Council, Australia, through its Metals Technology Centre, has conducted a series of seminars on the nicrosil versus nisil thermocouple system in capital cities throughout Australia. These seminars, which culminated in the latter half of 1982, were directed towards the adoption of the new thermocouple in science and industry in Australia. The authors of this report presented papers at the seminars on various aspects of the formulation, development, standardization, laboratory and industrial testing, and the commercial adaption and utilization of the nicrosil versus nisil system. This report, which is a consolidated summary of their presentations, constitutes the Proceedings of the seminars.

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CONTENTS

THE NICROSIL versus NISIL TYPE N THERMOCOUPLE: A COMMERCIAL REALITY

1. INTRODUCTION

1.1 In modern industrial processing, among the process variables to be controlled the temperature parameter is of utmost importance and can be very critical. In the metallurgical field, for example, temperature tolerances about some mandatory thermal-treatment temperature of as little as ±3°C are often specified. This tolerance range, which alludes to the temperature of material being treated, is expected to include a variety of errors in the pyrometric system, temperature differences in the workpiece(s) due to spatial and temporal variations of temperature in the heated enclosure, and differences of temperature between the workpiece(s) and the point of measurement. Moreover, failure to realize true temperatures within the specified tolerance bounds in industrial processing can have dire and costly consequences. These consequences may include wastage of material by initial rejection, premature failure or malfunction in service, and the need for costly pyrometric maintenance procedures.

1.2 Of all the process variables usually encountered, temperature is probably the most difficult to measure if the aim is to maintain the required degree of accuracy over a long period of time. Furthermore, temperature cannot be measured directly outside the laboratory, as it is an intensive property of materials fundamentally related to intrinsic kinetic energy of atomic structure. It is thus necessary to employ a transducer, a device which manifests some readily measurable physical property which is a function of temperature. This report is concerned with that most useful of temperature transducers, the metallic thermocouple.

1.3 In its simplest practical form a thermocouple comprises two wires, or thermoelements, of dissimilar materials joined at the ends to form a measuring-junction. With the measuring-junction located at the point where the temperature is to be measured, and the other ends of the thermoelements connected to the measuring instrumentation circuitry at a location called the reference-junction (see Fig. 1), the net open-circuit electromotive force generated between (not at) the two junctions of the thermocouple is a basic function of the temperature at the measuring-junction. This force is called the thermoelectromotive force, or thermal emf, and is the response of the thermocouple to the temperature interval it spans.

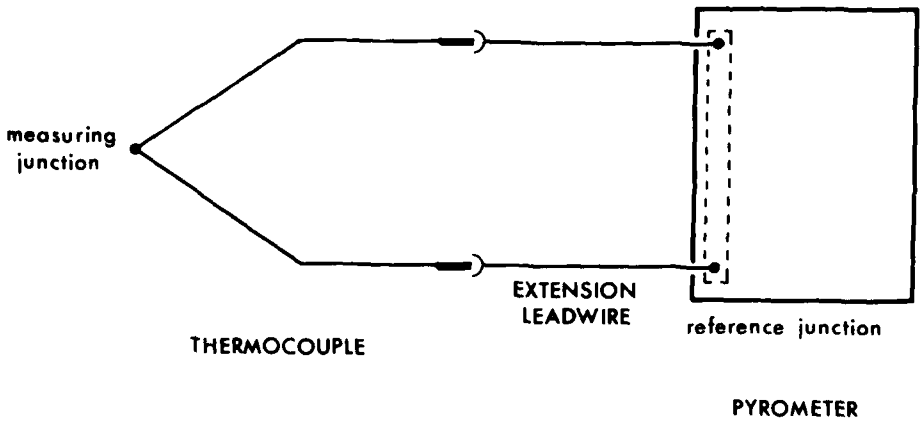

FIG. 1 The principal components of a typical installation for industrial pyrometry.

Of the three principal elements of a typical industrial pyrometric installation, namely the thermocouple transducer, the leadwires, and the measuring instrumentation, the least stable electrically is the thermocouple. Not only can the initial calibrations of thermocouple transducers of the same kind be different, but they can change in an insidious and generally cumulative way as temporal environmental interactions produce cumulative changes of an inhomogeneous kind in the structures and chemical compositions of the thermoelement materials concerned.

2. INHOMOGENEITY AND THERMAL EMF

2.1 Ideally, a metallic thermocouple comprises thermoelements of different individual elements or alloys which are homogeneous. That is, they feature no variations whatever in composition, structure, or state of mechanical stress. In this case, which is hypothetical, the thermal emf of a homogeneous thermocouple is a function only of the finite difference in the temperature of the measuring- and reference-junctions; it is dependent upon certain homogeneous characteristics of the individual thermoelement metals principally solution composition, metallurgical state of structure, and residual stress. It is thus possible to define thermoelectric properties of homogeneous thermoelements in terms of a single parameter, namely temperature, T. For example, the thermal emf - the thermocouple voltage between two conductors A and B - can be expressed in terms of the Seebeck coefficient -

$$e_{AB,o} = - \int_{o}^{T} S_{AB,o} \, dT \qquad \text{.... 1.}$$

where $S_{AB,o}$ is the relative Seebeck coefficient. Implicit in this relationship is the fact that thermal emf is generated in the temperature gradient and not at the thermojunctions.

2.2 Unfortunately, the homogeneous thermocouple is an hypothetical ideal. In the real world of science and industry, chemical, physical and metallurgical inhomogeneities are invariably generated in both the manufacture and subsequent usage of thermocouple alloys. As a consequence, the thermal emf of a practical thermocouple is also a function of temperature distribution in the temperature gradients along the individual thermoelements. This is because an inhomogeneous thermocouple is really made up of a very large number of individually different very small thermoelements intimately arranged in a series and parallel electrical array. The proposition of eqn. 1 clearly does not apply to this situation. Ternan [1], in developing an elegant solution to the problem of calculating the thermal emf in this most difficult case, states that -

$$\Delta e = - \int_{\ell_1}^{\ell_2} dT(\ell) \frac{\int \sigma (S - S_o) da}{\int \sigma da} \quad .... \ 2.$$

where Δe, the component of the total thermal emf e, due to inhomogeneity, $\Delta e = e - e_o$, where e_o is the 'ideal' emf,

S_o is the 'ideal' Seebeck coefficient,

S is the Seebeck coefficient of the inhomogeneous thermoelement,

σ is the electrical conductivity of the inhomogeneous thermoelement,

ℓ is the distance along the thermoelement, and the inner integrals are over the cross-section of the thermoelement.

2.3 The gradual and insidious increase in the magnitude of Δe in eqn. 2, namely that spurious component of the total emf of the thermocouple which is due to the progressive development of inhomogeneities in the thermoelements, is a prime cause of uncertainty, or errors of measurement, in modern-day pyrometry. It is therefore of the essence to examine what are the most common causes of inhomogeneities in base-metal thermocouple metals and alloys (see Table 1) which lead to the generation of these spurious thermal emfs. Particular reference is made below to the conventional nickel-base thermocouple alloys designated 'type K' by ANSI [2].

The causes of inhomogeneity in thermoelement metals and alloys are many and varied. Compositional inhomogeneities include those caused by the local segregation of component or impurity elements in alloy manufacture, the absorption of materials from the environment by solution or chemical combination, the loss of constituents by selective evaporation or chemical interaction, and the solution of elements produced by nuclear transmutation. Again, inhomogeneous metallurgical states can be caused by phenomena such as the thermal relief of residual internal stresses due to mechanical working, as well as structural ordering and recrystallization. Further, the effects of various physical phenomena such as magnetic transformations and electromagnetic fields can be quite influential.

Given that, within the constraints imposed by industrial production technology, inhomogeneities generated by the manufacturing process can be held minimal and fairly constant, it is those inhomogeneities developed in subsequent usage of thermoelements which give greater concern. ANSI standard letter-designated thermoelement alloys of the base-metal variety [2] are all plagued by the onset of spurious thermal emfs due to inhomogeneities which are developed during exposure at elevated temperatures in subsequent use.

There are three principal characteristic types and causes of such thermoelectric instability in the standard base-metal thermoelement materials [3-6]. In summary, these are -

(i) a gradual and generally cumulative drift in thermal emf on long exposure at elevated temperatures (Fig. 2). This is observed in all base-metal thermoelement materials and is due mainly to oxidation, and/or transmutation of elements during nuclear irradiation by neutrons. In the nickel-base ANSI types KP and KN thermoalloys the development of compositional inhomogeneities can be quite severe as reactive solute elements, in particular chromium, manganese and aluminium, are depleted by internal oxidation (Fig. 3).

(ii) a short-term cyclic change in thermal emf on heating in the temperature range ca 250 to 650°C (ca 525 to 925 K) which is observed in ANSI types KP (or EP) and JN (or TN and EN). This is believed to be due to some structural or electronic phenomenon, possibly of magnetic origin (Figs. 4 and 5).

(iii) a time-independent perturbation in thermal emf in specific temperature ranges. This is due to magnetic transformations which perturb the thermal emfs in type KN in the range ca 25 to 225°C (ca 300 to 500 K) and in type JP above ca 730°C (ca 1000 K) (Fig. 6).

Of these several characteristic causes of thermoelectric instability in the conventional base-metal thermocouples, high-temperature oxidation is potentially the most severe. This is because the thermoalloys concerned are of the solid-solution type and the thermal emf of such alloys is primarily dependent upon solute concentration [3]. This is illustrated in Figs. 7 and 8. The extent to which solute concentration is reduced by precipitation of solute oxides in the internally oxidized regions of conventional nickel-base thermocouple alloys is exemplified in Fig. 3.

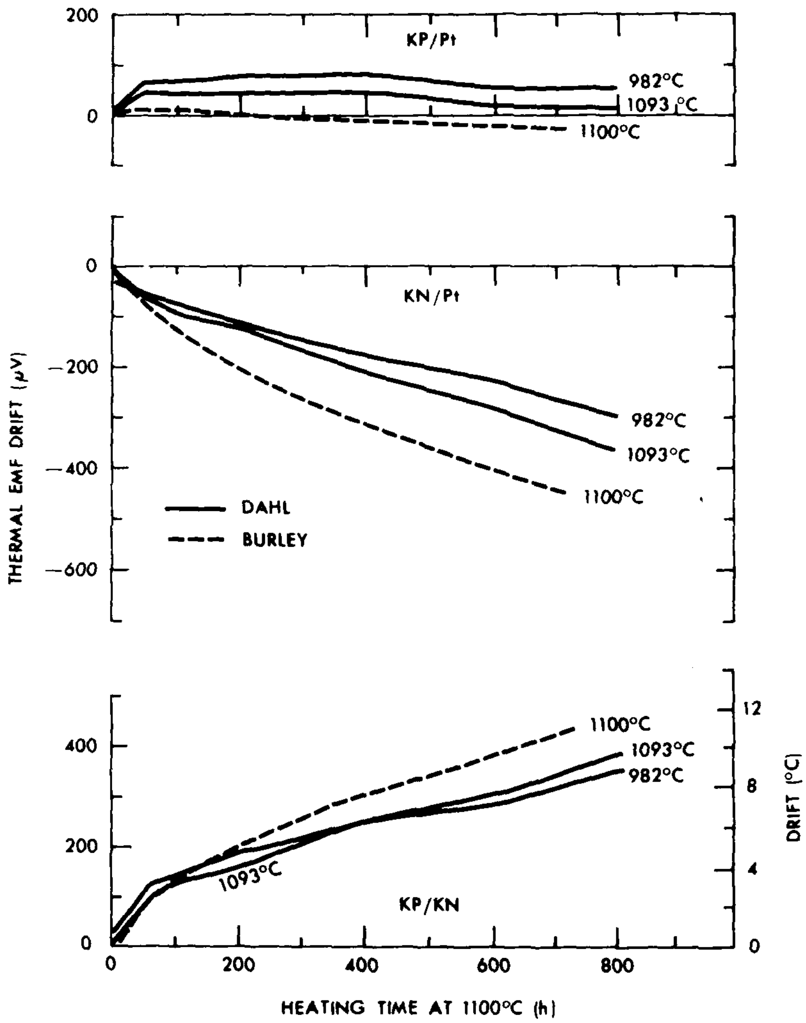

FIG. 2 Thermal emf drifts in conventional type K (2) thermocouples and in their respective KP and KN (2) thermoelements versus platinum on exposure in air at a constant temperature of 1100°C. (3) Dahl's data was published in 1941. (3)

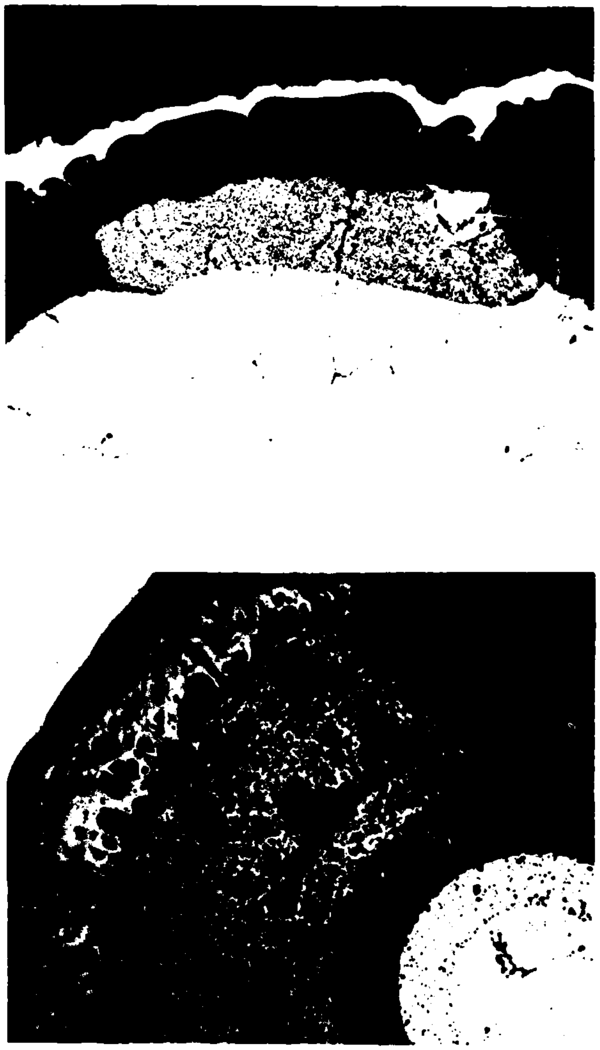

FIG. 3 Oxide structures in conventional type K thermocouple alloys. These microstructures result from exposure in air for 800 h at a constant temperature of 1200°C. The outer white annular zones are layers of electrodeposited copper applied to support the fragile scales.

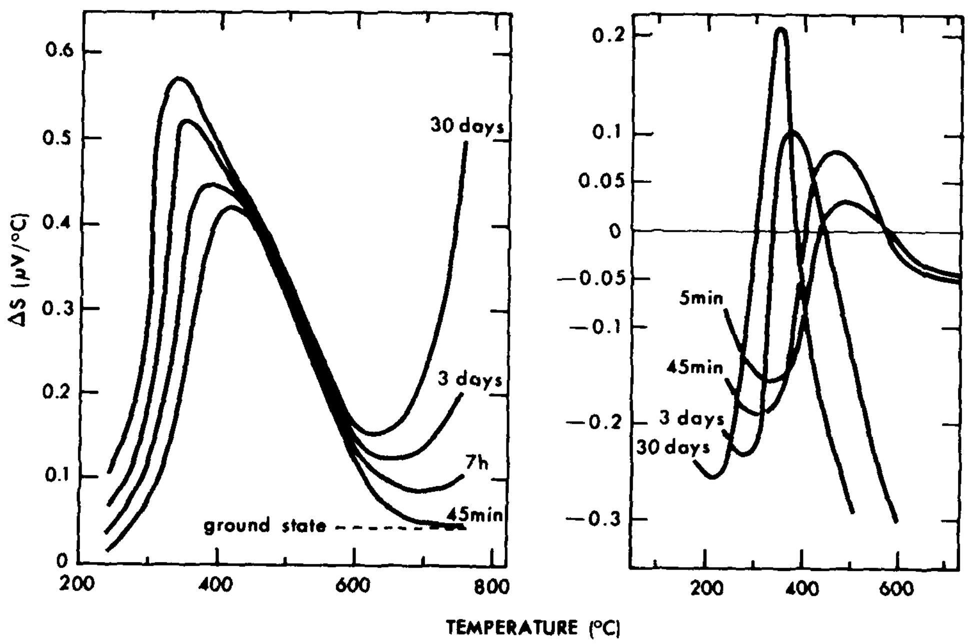

FIG. 4 Changes in the Seebeck coefficient (ΔS) of a typical type KP thermoelement versus platinum on initial heating, as a function of constant ageing temperature for the indicated times. (8)

FIG. 5 Changes in the Seebeck coefficient (ΔS) of a typical type JN(TN,EN) thermoelement (2) versus platinum on initial heating, as a function of constant ageing temperature for the indicated times. (8)

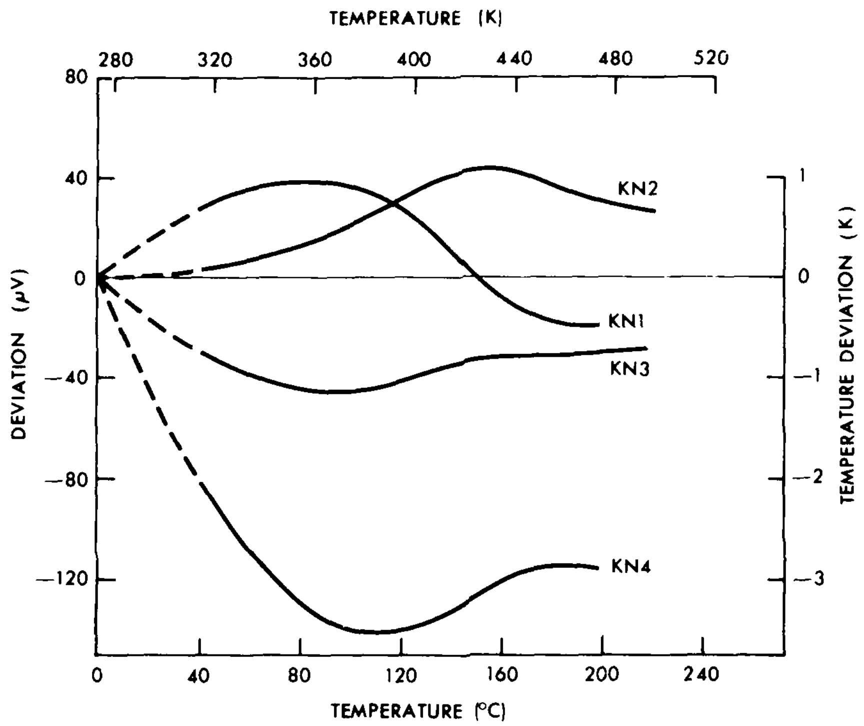

FIG. 6 Deviations of the measured values of the thermal emf's of several type KN thermoelements versus platinum from NBS reference table values. (4) The real variants of the type KN nominal compositions given in Table 1 are -

KN1:-	Ni-3.02Mn	-1.90Al	-1.19Si	-0.41Co
KN2:-	1.67	1.25	1.56	0.72
KN3:-	-	-	2.50	1.00
KN4:-	0.43	-	2.39	0.23

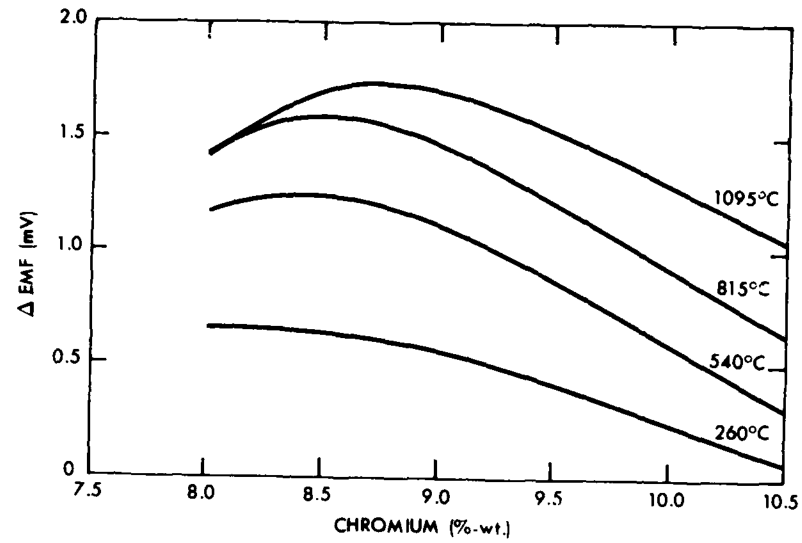

FIG. 7 Effect of chromium in a type KP thermoalloy on the thermal emf at various temperatures. (13)

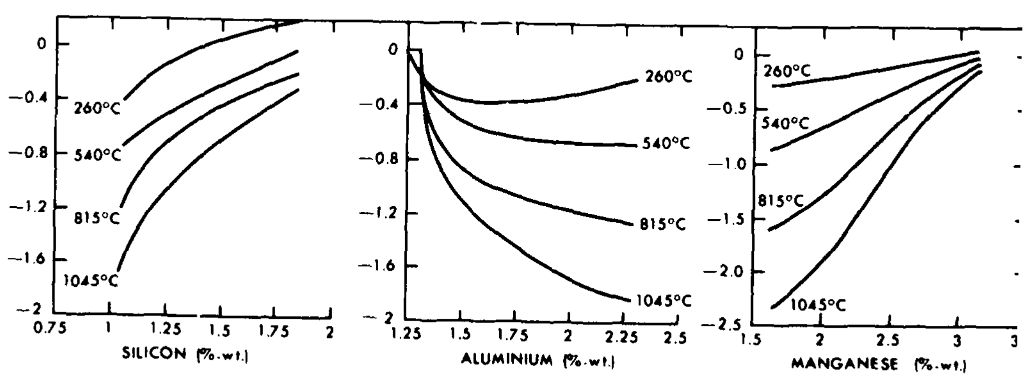

FIG. 8 Effects of manganese, aluminium and silicon in a type KN thermoalloy on the thermal emf at various temperatures. (13)

3. THE NICROSIL versus NISIL THERMOCOUPLE

3.1 Research at Materials Research Laboratories has led to the formulation and development of a new pair of highly-stable nickel-base alloys for thermocouples called NICROSIL (positive) and NISIL (negative)* . Their specific compositions are given in Table 1.

TABLE 1. Base-metal Thermoelements

ALLOY	ANSI TYPE[a]	Chemical Composition, wt.-%								GENERIC NAME
		Cu	Fe	Ni	Cr	Si	Mn	Al	Mg	
POSITIVE	TP	100								COPPER
	JP		100							IRON
	KP, EP			90	9.5	0.5				CHROMEL
	(NP)			84.4	14.2	1.4				NICROSIL
NEGATIVE	TN, JN, EN	55		45						CONSTANTAN
	KN			94		1	3	2		ALUMEL
	(NN)			95.5		4.4			0.1	NISIL

[a] NP and NN are letters widely used to typify nicrosil and nisil alloys, but are not yet official designators of ANSI (2). See footnote at page 21.

The nicrosil and nisil thermocouple alloys show greatly enhanced thermoelectric stabilities relative to the ANSI standard base-metal thermocouple alloys [2], because their compositions are such as to virtually eliminate or substantially nullify the causes of thermoelectric instability described above. This is achieved primarily by increasing component solute levels (chromium and silicon) in a base of nickel above those required to cause a transition from internal to external modes of oxidation (see Fig. 9), and by selecting solutes (silicon and magnesium) which preferentially oxidize to form diffusion-barrier films. Thermal emf drifts due to neutron irradiation, such as occur in nuclear reactors used in electricity generation, also have been markedly attenuated in both nicrosil and nisil by excluding from their specific compositions readily transmutable elements such as manganese, cobalt and copper which are found in nickel-base type K alloys.

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* The full scientific rationale of the original formulations of the NICROSIL and NISIL alloys is given in the U.S. National Bureau of Standards Monograph 161 [3].

The thermal emf instabilities of the short-term cyclic kind occurring in type KP (or EP) alloys have virtually been eliminated in nicrosil by setting the chromium content at 14.2 wt.%. This result is illustrated in Figs. 10 and 11. The increase in the silicon content of nisil to 4.4 wt.% has suppressed the magnetic transformation of this new alloy to below room temperature (see Fig. 12).

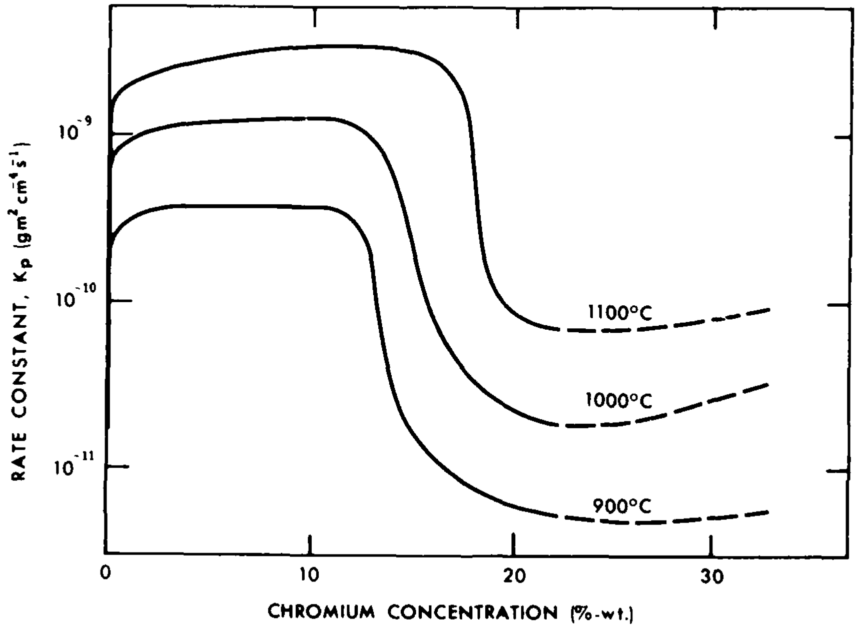
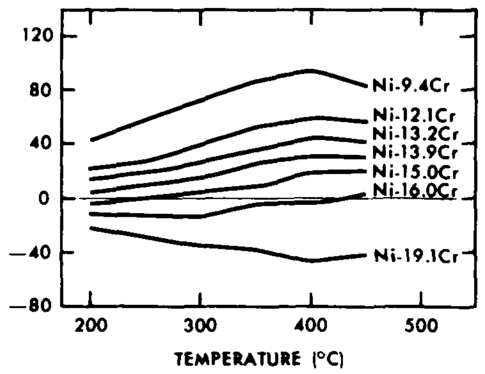


FIG. 9 Composition dependence of the parabolic rate constant (K_p) in the oxidation, in 10 kPa O_2, of alpha Ni-Cr alloys at various temperatures. (3)

Note: The marked changes in oxidation rate are associated with the transition from internal to external modes of oxidation referred to in Section 3.1 of the text.



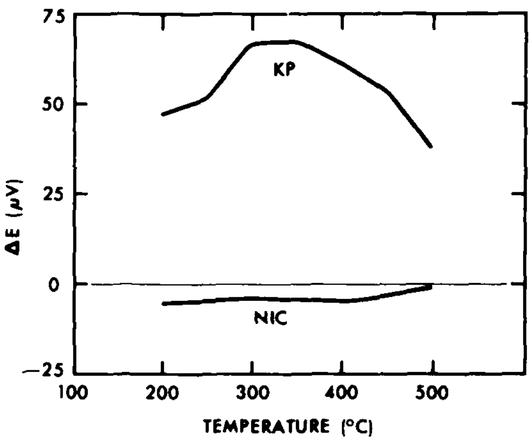


FIG. 10 Changes in the thermal emf's of several Ni-Cr alloys in the alpha range 9 to 20Cr during a heating (to 450°C) and cooling cycle following water-quenching from 1050°C. The changes are deviations in the emf's versus platinum on cooling from the values measured during heating. (3)

FIG. 11 Changes in the calibration of type KP and nicrosil thermoelements versus platinum, in terms of the differences (ΔE) of the calibration values obtained during the cooling portion of the calibration cycle from those obtained during the heating portion (emf on cooling minus emf on heating). The samples were held at 500°C (773 K) for one hour before cooling. (3)

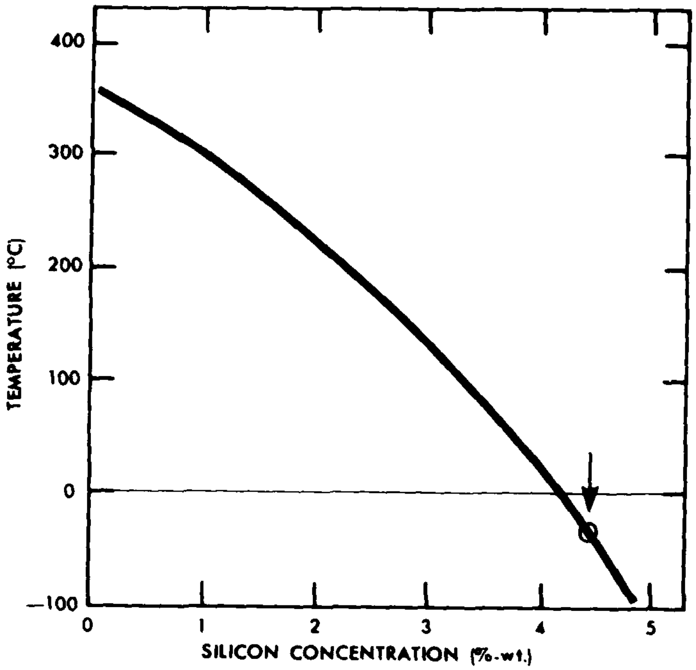


FIG. 12 The effect of silicon on the ferro- to para-magnetic transformation in alpha-nickel silicon alloys. The arrow marks the position of nisil.

3.2 The basic thermoelectric reference properties of nicrosil and nisil have been extensively studied by both Materials Research Laboratories and the U.S. National Bureau of Standards [3]. Of these various properties, some are dealt with below in detail because they are of major importance.

The thermal emf of nicrosil versus nisil is of about the same magnitude as that of the conventional nickel-base thermocouple system of type K (see Fig. 13). The relatively high output signal thus provided makes nicrosil versus nisil an eminently suitable transducer for the actuation of the full range of electronic potentiometers, micro-processors and computers used in modern-day pyrometric instrumentation. It is to be noted, however, that the shape of the emf-temperature characteristic curve of nicrosil versus nisil is significantly different from that of type K, and this has necessitated the publication of new tabular values of the thermal emf of nicrosil versus nisil as a function of temperature. Such tables have been published by the U.S. National Bureau of Standards (NBS) [3] and by the American Society for Testing and Materials (ASTM) (see section 4.3.1).

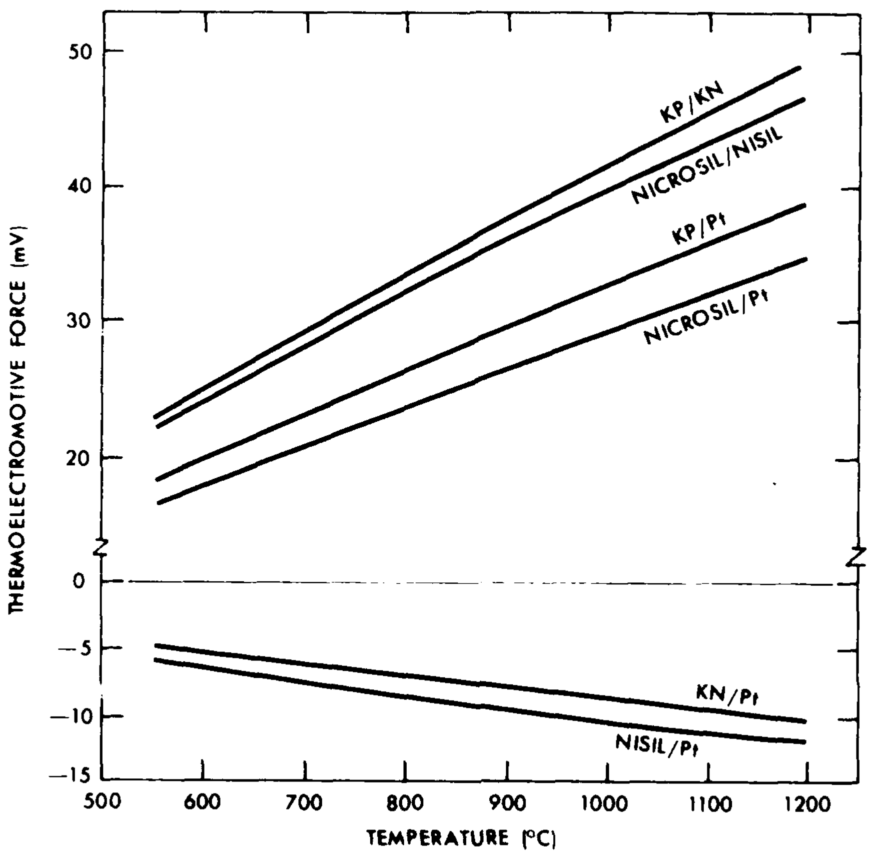


FIG. 13 Thermal emf's of nicrosil versus nisil and type K thermocouples, and of their individual thermoelements versus platinum.

3.3 There is abundant evidence [3, 5-8] that the long-term thermoelectric stability of the nicrosil versus nisil thermocouple under oxidizing conditions is markedly superior to the stabilities of all the other conventional standard base-metal thermocouples which are letter-designated by ANSI [2]. This superiority is illustrated graphically, in terms of relative thermal emf drifts for a range of different thermoelement wire sizes, in Figs. 14-17 and in Table 2 [8]. Of considerable significance, in the field of scientific and industrial pyrometry, is the fact that in oxidizing atmospheres, the thermoelectric stability of the nicrosil versus nisil thermocouple, in thermoelement wire sizes not finer than about 10 AWG (see Figs. 16 and 17, and Table 2) is about the same as that of the rare-metal thermocouples of ANSI types R and S [2] up to about 1200°C [8].

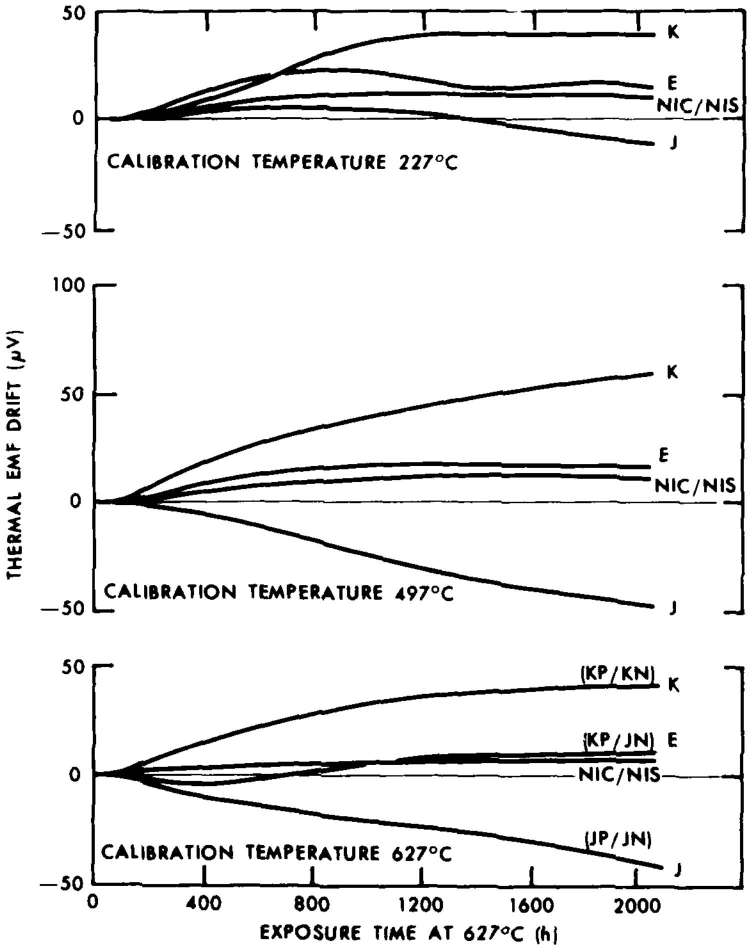


FIG. 14 Long-term thermal emf drifts in air, at three calibration temperatures, for 14 AWG thermocouples in ANSI types E, J, K and nicrosil/nisil. The drifts are changes from emf output values existent after 100 hours of exposure at a constant ageing temperature of 627°C. (8)

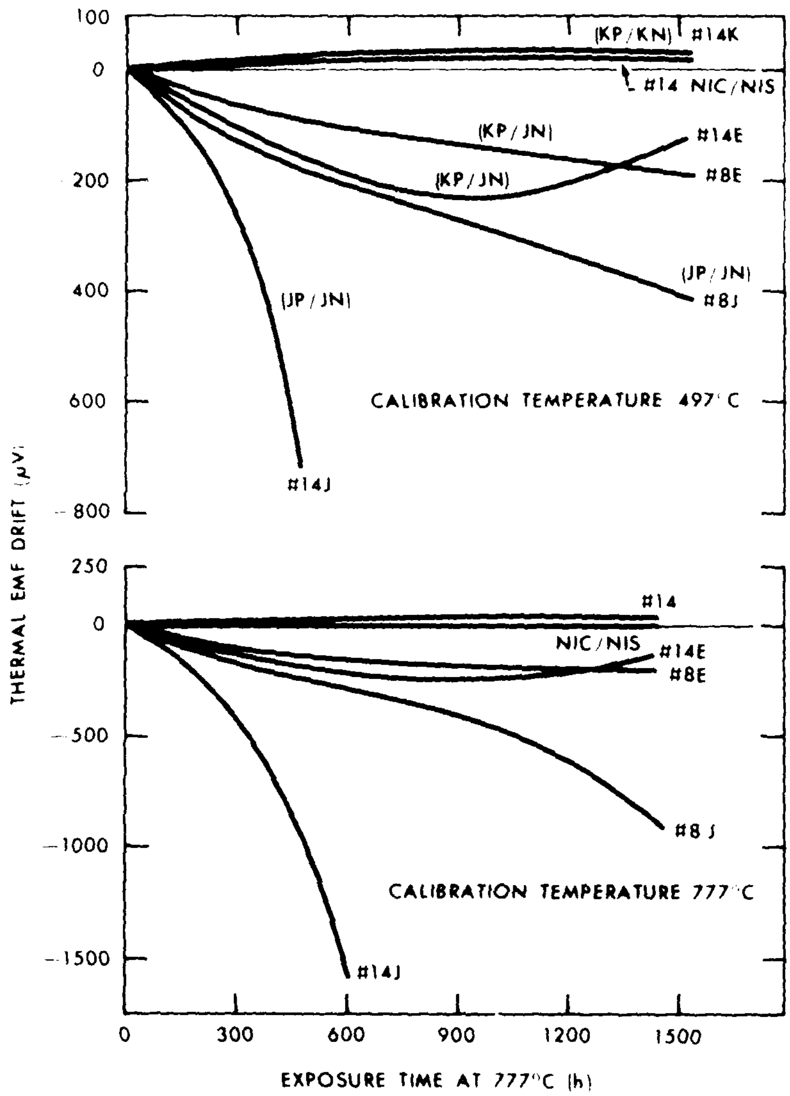


FIG. 15 Long-term thermal emf drifts in air, at two calibration temperatures, for 14 AWG (#14) nicrosil/nisil and E, J and K thermocouples. The thermal emf drifts for 8 AWG (#8) E and J thermocouples are also given. The drifts are changes from emf output values existent after 20 hours exposure at a constant ageing temperature of 777°C. (8)

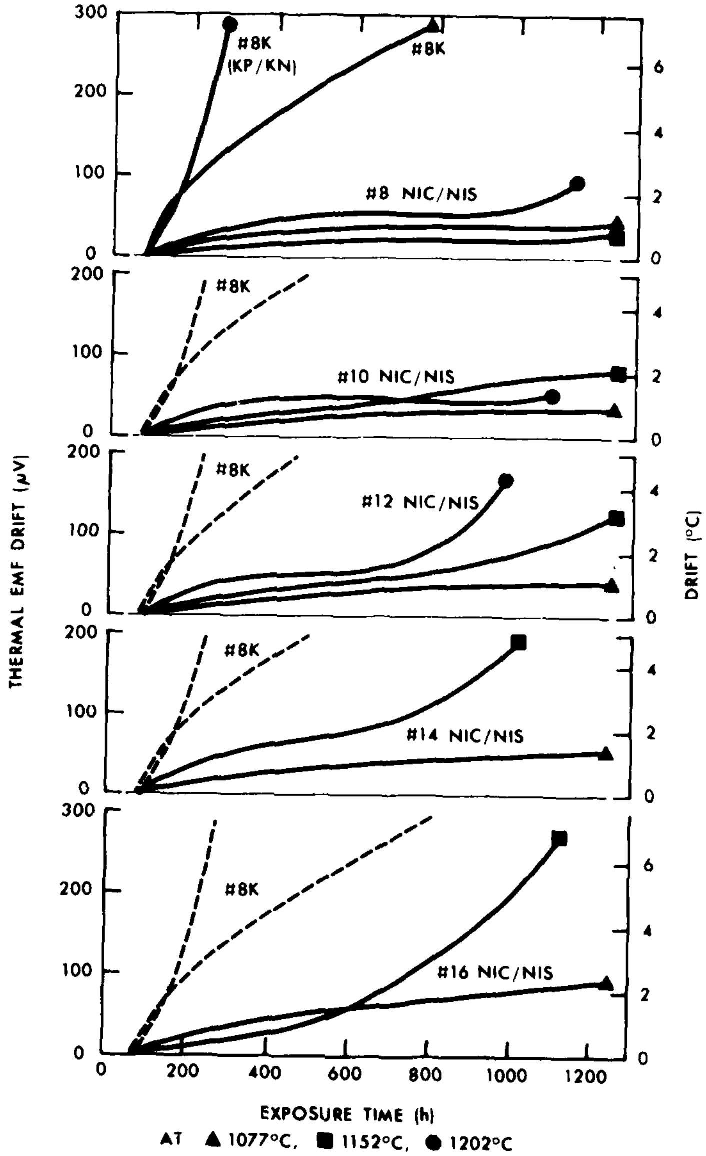


FIG. 16 Long-term thermal emf drifts in air, at three constant ageing (and calibration) temperatures for nicrosil/nisil thermocouples in five wire gauges (#). Corresponding thermal emf drifts for 8 AWG (#8) type K thermocouples at two of these temperatures are also given. The drifts are changes from emf output values existent after 80 hours of exposure at the constant ageing temperature. (8)

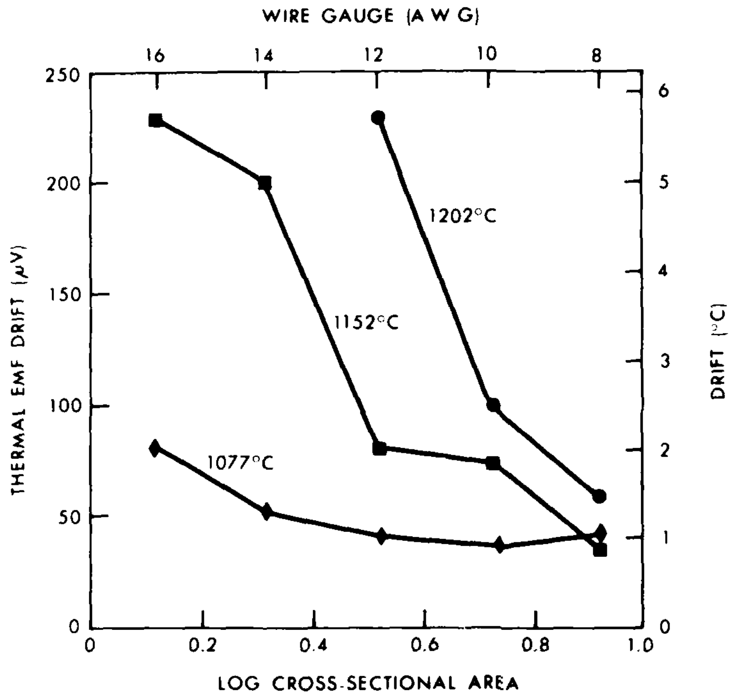


FIG. 17 The relationship between total thermal emf drift (after 1000 hours of exposure in air at each of three test temperatures) and cross-sectional area of nicrosil/nisil thermocouple wires. The drifts are changes from emf output values existent after 80 hours of exposure. (8)

3.4 The oxidation of thermocouple alloys at elevated temperatures can also occur in a nuclear radiation environment, such as in the generation of electrical energy using nuclear reactors. In these circumstances, particularly where neutron irradiation is encountered, the elemental solute components of such thermocouple alloys can transmute. This process can occur, of course, at any temperature and in the absence of any other primary cause of thermal emf instability such as oxidation. Normally, in a nuclear reactor, oxidation and transmutation can occur simultaneously, and the effects of these two processes on thermal emf drift are then additive.

TABLE 2. A comparison of drifts[a] in nicrosil/nisil and ANSI type K thermocouples at temperatures above 1000°C.

Thermocouple materials	Wire gauge AWG No.	Drift after 1000 h at the three temperatures shown					
		1077°C		1152°C		1202°C	
		μV	°C	μV	°C	μV	°C
type K	8	350	9.2	c	-	c	-
nicrosil-nisil	8	42	1.1	36	1.0	59	1.6
nicrosil-nisil	10	37	1.0	75	2.0	101	2.7
nicrosil-nisil	12	41	1.1	81	2.2	230	6.2
nicrosil-nisil	14	52	1.4	200	5.3	b	-
nicrosil-nisil	16	79	2.1	230	6.1	b	-

a The thermal emf drift is given in μV. The temperature drift is given in the equivalent number of degrees Celsius, the relevant references being NBS monograph 125 (4) for the type K thermocouples and NBS Monograph 161 (3) for the nicrosil/nisil thermocouples

b No data were generated; previous studies (14) indicate that thermocouples of these gauges have shortened lives at this temperature

c The 8 AWG type K thermocouples failed after about 730 h at both 1152°C and 1202°C. The last measurements taken prior to failure showed drifts of 495 μV (13°C) and 615 μV (17°C), respectively

Transmutation of the components of base-metal thermocouple alloys is usually accompanied by cumulative long-term drifts in thermal emf [8]. In the case of the conventional type KN alloy, for example, elemental components such as manganese and cobalt undergo substantial transmutation. Since these elements are not present in the compositions of nicrosil and nisil, the new thermocouple will therefore show less instability of thermal emf in the nuclear environment than the conventional type K alloys. The use of nicrosil/nisil thermocouples in nuclear reactor applications is thus to be advocated.

4. INDUSTRIAL AND COMMERCIAL DEVELOPMENT

4.1 Introduction

The ultimate industrial and commercial success of the nicrosil versus nisil thermocouple depends, as with any other invention, on a number of important factors which go far beyond the scientific solution of the initial technical problem. Indeed, in the case of this new thermocouple, these further factors have proven to be more formidable obstacles than any encountered in the course of the inventive process.

The invention of an improved product is of no real use unless the product is commercially developed, adopted and used. The task of persuading the world to accept a new thermocouple system, no matter how good, is no easy one. The full commercial exploitation of the nicrosil versus nisil system has involved the successful surmounting of a series of obstacles which, seen in another light, were crucial goals. These goals, vitally interrelated and interdependent, can be considered under a number of discrete headings -

- Alloy manufacture
- Promulgation as a Standard
- Independent Validation
    - Laboratory Tests
    - Industrial Trials
- Commercial Availability
- Adoption and Use

4.2 Alloy Manufacture

The active collaboration of thermocouple alloy manufacturers around the world has been a vital factor in the development of the nicrosil versus nisil thermocouple so far. From the production of the early experimental alloys in the late 1960's, through the melting and drawing of the NBS/MRL prototype alloy samples [3], to present-day commercial batches, the evidence points to the very highest quality, purity and reproducibility. Comparisons of the compositions and thermal emf outputs of several alloy melt-batches of nicrosil and nisil alloys, selected at random from recent commercial production, can be made from the data given in the tables in Appendix I.

4.3 Promulgation as a Standard

4.3.1 The ASTM, through its Committee E-20 on Temperature Measurement, has shown considerable interest in nicrosil versus nisil, and has kept matters relating to the development, availability and use of the new thermocouple under continual review.

Recently, relevant subcommittees of ASTM E-20 have produced several publications containing information on the properties and characteristics of the nicrosil versus nisil thermocouple. A document quoting several of the emf-temperature tables from NBS Monograph 161 [3] was published [9] for information. A Proposed ASTM Standard, having a more formal status, is in course of preparation [10]. Again, in the recently published third edition of the ASTM Manual on the Use of Thermocouples in Temperature Measurement [11], various properties and characteristics of nicrosil versus nisil are summarized in the section on non-standardized thermocouple types.

4.3.2 The ASTM is currently giving consideration to the standardization of the nicrosil versus nisil thermocouple in the sense of promulgation as an American Standard Thermocouple. It appears that the E-20 Committee has now recommended a letter-designation for the new thermocouple [7]. It is to be noted that the actual task of assigning such letter designations for standard thermocouples is carried by the ANSI Committee MC-96, which is sponsored by the Instrument Society of America.*

4.4 Independent Validation

4.4.1 Laboratory Tests

Since the early 1970's the performance of the nicrosil versus nisil thermocouple has been the subject of a considerable number of studies at various government and private laboratories around the world. In these studies the performance of the new thermocouple was compared, in most cases, with that of conventional Type K tested under very similar experimental conditions. Burns, of the US National Bureau of Standards, has given a succinct summary of the major of these tests at the recent Sixth Temperature Symposium in Washington, D.C. [7]. His review can be regarded as authoritative, independent and disinterested.

For the purposes of his review, Burns separated the studies into two groups, namely those of bare-wire thermocouples assembled in hard-fired ceramic insulators and those of thermocouples fabricated in metal-sheathed, compacted-ceramic insulated form. Most of these studies were conducted with the thermocouples heated in air. Of the 21 investigations by various workers of high international repute which are cited, 12 involved bare-wire thermocouples and 9 involved mineral-insulated integrally-sheathed thermocouples. In the former case, there was no exception to the findings that the nicrosil versus nisil thermocouple was significantly superior to the type K thermocouple in thermoelectric stability. In the latter case, only two workers reported nicrosil versus nisil to be inferior and then primarily for reasons of inappropriate construction.

Burns concludes his review by opining that it can be expected that the nicrosil versus nisil thermocouple will find increasing use in both

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* A letter designation (type N) was approved by Committee SP-1 of the Instrument Society of America on November 15, 1983.

present and new industrial processes because of its advantageous characteristics, and that this new thermocouple will be a valuable addition to the family of standardized letter-designated (ANSI) thermocouples.

4.4.2 Industrial Trials

Again since the early 1970's, the performance of the nicrosil versus nisil thermocouple has been the subject of a number of trials in practical industrial applications, both in Australia and Overseas. The driving force in mounting such trials has usually been frustration over the limitations in performance imposed by the conventional ANSI letter-designated base-metal thermocouples (see Table 1). The usual ploy in such trials has been to incorporate nicrosil versus nisil thermocouples in industrial pyrometric installations, and then monitor their comparative performance over a period of time. Although it is known that industrial trials of the new thermocouple have been carried out in a number of different countries including the U.S.A., Japan, the U.K. and France in the Western World, Australia has taken a lead in the early procurement and trialling of various commercial products which go to make up pyrometric installations for the nicrosil versus nisil system.

In 1971 the Managers of the Defence Production Factories, in the Australian Government Department of Supply, agreed to co-operate in a program for the adoption of the nicrosil versus nisil thermocouple system for all relevant thermal-treatment processes. In 1976 a Joint Working Party (JWP) was set up, by the Department of Defence and the Department of Productivity, to resolve technical problems arising during the introduction of the new thermocouple. The JWP succeeded in resolving a number of such problems, and produced a Test Procedure [12] to govern the industrial trials that were planned to take place in the various Defence Factories (now part of the Department of Defence Support).

Part of the effort of the JWP was to set up conditions favourable to the involvement of the private sector of industry in Australia. The aim was to persuade this sector not only to become users of nicrosil versus nisil thermocouples but also to participate in their supply. In the event, several Australian firms supported these efforts. The JWP also offered to provide, in support of trials work in the private sector, limited quantities of nicrosil/nisil thermocouple wire and duplex extension lead in return for trials performance data. Arrangements were also made to provide, on loan for the duration of a trial, calibrated rare-metal reference-thermocouples and pyrometric instruments converted to suit the nicrosil versus nisil thermal emf characteristics. A specification was drawn up governing the supply of rod-stock of both alloys, and a contract was let to Driver-Harris Australia Pty. Ltd., Epping, Victoria, to supply such stock and to draw wires down to specified sizes. This alloy rod-stock, when eventually obtained, showed a high degree of conformity with the tabular values of thermal emf-temperature for nicrosil versus nisil given in NBS Monograph 161 [3]. The thermoelement wires drawn from the rod-stock exhibited a high degree of compositional homogeneity and compliance with the chemical formulations specified in NBS 161.

To conform with Australian Standard practice, and to assist in wire identification, preferred metric sizes of 2.8 mm, 1.4 mm and 0.5 mm diameter were chosen from the ASA R20 range. The first two sizes afforded differentiation from the commonly used gauges of conventional base-met thermocouple wires. Olex Pty. Ltd. produced a PVC insulated and shea version of duplex thermocouple wire, while A.F. Bambach Pty. Ltd. proc silicone-impregnated-fibreglass insulated and sheathed version using r and nisil thermoelement wires supplied from Departmental stocks. Mine insulated metal-sheathed thermocouple cable incorporating nicrosil anc conductors is now being produced by Pyrotenax Australia Pty. Ltd., wit 310 stainless steel sheathing.

A number of industrial trials of nicrosil versus nisil therm have now been successfully completed in Government Defence Production Factories in Australia. Several examples of such trials, involving c types of thermal-treatment installations, are described in Appendix I] can be seen that, in all cases, nicrosil/nisil thermocouples showed significantly enhanced performance.

Following the trials in the Government Factories, a number n been carried out by various manufacturing firms in the private sector industry in Australia. A few important examples of these trials, toc with the results obtained, are described in Appendix III. Once again, enhanced performance of nicrosil versus nisil thermocouples is demonst

Finally, some salient examples are given, in Appendix IV, of carried out in other countries which have culminated in the adoption c nicrosil versus nisil thermocouples in important sectors of industry, example, the manufacture of electronic computers and the generation of electricity by both conventional and nuclear means.

All the trials cited in Appendices II to IV amply demonstrat considerable advantages which accrue from the use of nicrosil versus r thermocouples in industry. This demonstration is not just the result process of selection of favourable examples. Indeed, there is no knc in a much wider field of examples, where industrial trialling has not results greatly in favour of the new thermocouple system.

5. COMMERCIAL AVAILABILITY, ADOPTION AND USE

5.1 *Introduction*

Let us assume that a potential user decides to introduce th nicrosil versus nisil thermocouple system into his plant and processe can this be achieved? Until recently, the solution had not been sim because most of the relevant technical literature had not been made a commercially, and the thermocouple itself had been supplied to indust Australia only on a trial basis by the Departments of Productivity an Support.

Today the situation is different. The nicrosil versus nis thermocouple, together with its allied pyrometric instrumentation anc accessories, is commercially available in Australia from a number of suppliers. Thus the initial restriction on supply has changed to ready availability. Complete availability will depend on a number of factors, including the future demand from industry, the commercial reality of amortising engineering costs associated with modifying existing instrumentation and developing new systems, and the maintenance of adequate stocks of the relevant supplies in Australia.

Before such a product can be effectively marketed, it is usual and desirable that it comply with a relevant standard or code. In Australia, most thermocouples and associated equipment comply with ANSI Standard Publication MC96.1 [2]. This Standard does not yet include the nicrosil versus nisil thermocouple, although hopefully it will in the near future (ref. section 4.3). In the interim, one instrument company, the Leeds & Northrup Company (L & N), has established and published a set of identification colours and a letter-designation utilising ANSI guidelines. In Australia and the U.S.A., it would seem that this interim identification system is generally accepted. Fig. 18 defines the arrangement. The tabular values of the thermal emf of the nicrosil versus nisil thermocouple are available in Australia in book and sheet form, free of charge or at a low cost, from commercial suppliers.

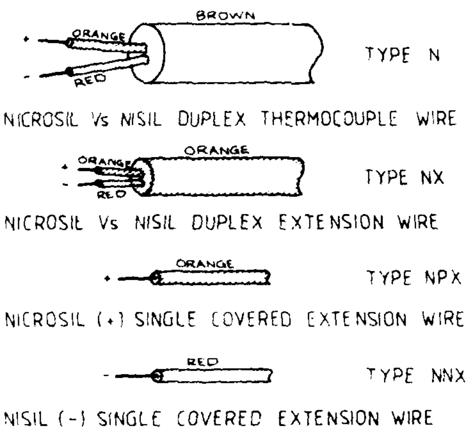

FIG. 18 Interim identification code for nicrosil versus nisil thermocouple and extension wires (insulated and covered)

As indicated in Fig. 1, three basic components comprise a typical industrial pyrometric monitoring system, namely the thermocouple transducer or sensor, the thermocouple extension leadwires, and the indicating, recording, controlling, or logging instrumentation. A typical practical arrangement is shown in Fig. 19. A range of such components and equipment is already available commercially in Australia.

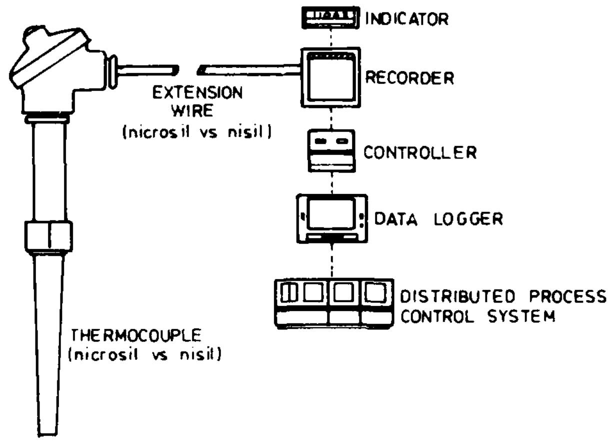

FIG. 19 Practical arrangement of the basic components of a typical pyrometric installation.

Most industrial users will approach the introduction of the nicrosil versus nisil thermocouple system with caution until they prove for themselves, or are convinced from an evaluation of results obtained by other users in a similar process or situation, that the new system has something of tangible advantage to offer. Thus, a likely first step is the introduction of the new thermocouple on a pilot basis into existing plant. The following sections of this report describe the availability and likely cost, when sourced from within Australia, of nicrosil versus nisil sensors, extension wire(s) and indicating, recording, controlling and logging instrumentation. Such components are likely to be used in industry in a variety of situations, including adaption to existing systems and using new technology such as a computer.

5.2 Sensors

5.2.1 Thermocouple wire (non-insulated)

Bare nicrosil versus nisil thermocouple wires are available in Australia from a number of pyrometric and instrument supply companies. The wires are usually sold by the double metre and are stocked in the traditional wire gauges as well as in metric sizes, both of which suit existing insulators and fittings.

5.2.2 *Thermocouple wire (insulated)*

Nicrosil versus nisil thermocouple wires are available in a variety of duplexed cable forms which incorporate glass, teflon or other insulating materials. Such cables can readily be fabricated into thermocouples for use principally in testing and research work. Colour coding mostly complies with the L & N nominated colour scheme illustrated in Fig. 18.

5.2.3 *Fabricated thermocouple assemblies*

These units are available on short delivery, in all the traditional forms, from most commercial suppliers. Some comments on the welding of nicrosil to nisil to form a measuring-junction are presented in Appendix V.

5.2.4 *Mineral-insulated integrally-sheathed thermocouple cable and assemblies*

This type of nicrosil versus nisil thermocouple cable, and ancillary componentry, is readily available in Australia in 3 mm and 6 mm overall diameter, with 310 stainless steel and 601 inconel sheathing. Hence, lengths of this base materiel can be quickly supplied to potential users. Other sheath diameters and sheathing materials are available on special order from overseas sources. Pyrotenax Australia Pty Ltd is presently investigating the feasibility of producing this type of cable with nicrosil and/or nisil sheathing for prolonged operation to 1250°C.

5.2.5 *Cost*

To make valid cost comparisons, it is necessary to compare equivalent products. If, then, one is considering bare 3.25 mm diameter (8 AWG) nicrosil and nisil wires, which typically are used to fabricate thermocouples for prolonged exposure to oxidising atmospheres at, say, 1200°C, these wires should be compared with the nearest performing equivalent. This is a rare-metal thermocouple, say ANSI type R (platinum-13% rhodium versus platinum), because the nicrosil versus nisil thermocouple would provide equivalent performance in terms of longevity and thermoelectric stability in such applications. Hence, in this example, bare nicrosil versus nisil thermocouple wire is, on a linear basis, typically 25 times cheaper than its platinum equivalent.

To compare nicrosil versus nisil with conventional nickel-base type K wire for such an application is not very rational, as the life expectancy and thermal emf stability of nicrosil versus nisil is considerably greater. At present, however, such a comparison shows that nicrosil versus nisil is more expensive than type KP versus KN by, typically -

bare wire	-	10 to 20%,
duplex covered wires	-	50 to 80%,
fabricated thermocouple assemblies	-	nil, and
mineral-insulated integrally sheathed assemblies	-	10 to 15%.

Two important factors relevant to these costs are to be noted. First, the cost differentials are only temporary; they are related to initial development costs and minimal production runs of nicrosil and nisil obtaining at this time. As industrial demand increases, the unit price of nicrosil versus nisil wires will quickly fall, to be fully competitive with conventional nickel-base thermocouple wires. Secondly, and in any event, thermocouple wires in a base-metal fabricated thermocouple represent only a very small part (as little as 5%) of the total thermocouple assembly cost.

5.3 *Extension Leads and Accessories*

5.3.1 *Extension leadwire cable*

Nicrosil versus nisil extension leadwire cable, colour-coded to the L & N nominated system, is available from several suppliers most commonly in duplex PVC-insulated form. Multi-cored extension cable, and cables with various insulating materials, metal shielding screens, etc., are available from overseas. Initial unit costs appear to be, typically, twice those for similar extension leadwire cabling with type K conductors. Installations where the extension cabling operates at elevated temperatures are being serviced with readily available glass-insulated nicrosil versus nisil thermocouple cable, which has a unit cost similar to PVC-insulated extension leadwire cable.

It should be noted that no compensating leadwire cable (lower-cost alloys with similar EMF versus temperature characteristics) is planned or recommended for use with the nicrosil versus nisil thermocouple system.

5.3.2 *'Quick-Disconnectors'*

Conventional quick-disconnect plugs and sockets constructed from nicrosil and nisil alloys do not appear in 1982 to be commercially available in Australia. This is due to the lack of an ANSI standard colour-code for the new thermocouple and also to the considerable investment cost of setting up, manufacturing and stocking these components, particularly when demand is minimal. It is expected that when a standard colour is assigned, and demand grows, nicrosil versus nisil quick-disconnect plugs and sockets and associated accessories will soon become commercially available.*

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* This situation is changing in mid-1983. Several pyrometric firms are now stocking these units, generally coloured orange.

5.4 *Instrumentation*

5.4.1 *General*

The procurement of new pyrometric instrumentation or the modification of existing instrumentation to monitor the nicrosil versus nisil thermocouple sensor may prove somewhat more difficult, and may be significantly more expensive, than replacing the thermocouple sensor itself. Potential users, therefore, should carefully review each application to determine the most suitable approach.

If the application is a new installation, the provision of new instrumentation (most likely microprocessor-based), together with new nicrosil versus nisil extension leadwires and thermocouples, is the apt solution. In established plants, however, where the existing instrumentation is considered to be satisfactory and reliable, it may be more economical simply to modify the pyrometers for actuation by nicrosil versus nisil thermocouples. Even so, the existing extension and/or compensating leadwires will have to be replaced.

Under some circumstances, however, for example where a type K thermocouple is to be replaced by a nicrosil versus nisil thermocouple primarily for longer life expectancy at elevated temperatures (say, 1150°C), it may be appropriate to install the nicrosil versus nisil thermocouple and instrumentation and yet retain the existing fixed installation of type K extension or compensating leadwire cable. This scheme assumes that a longer thermocouple life (and hence cost savings), and not improved pyrometric accuracy, is the principal aim. Further, it assumes that the temperatures of the junctions where the nicrosil versus nisil thermocouple is joined to the existing extension or compensating leadwire cable, and where the existing cable is joined to the instrument, are moderately stable and not greatly elevated. Appendix VI presents an analysis of the estimated errors that are to be expected when nicrosil versus nisil thermocouple sensors and instrumentation are used with existing ANSI types J, K, R, S or T extension or compensating leadwires at various ambient temperatures.

It is emphasized however, that *nicrosil versus nisil extension wire* should be preferred for use whenever and wherever possible.

5.4.2 *Modifying existing instrumentation*

Most pyrometers now in use in industry, provided they are adequate and reliable, can be modified simply and inexpensively to operate in conjunction with nicrosil versus nisil thermocouples. Initially, an approach should be made to the manufacturer of the equipment, or his local representative, to seek advice. Several Australian companies supplying such instruments have already developed the capability of quickly and economically modifying most of their existing lines (some up to twenty years old) to measure nicrosil versus nisil thermal emf's. Many suppliers, of course, in particular those that vend lower-priced equipment, may not have this expertise or consider it to be commercially economical to convert existing instruments. Even so, in most cases, the end-user has the option of having his equipment modified by a competent instrument technician.

The main modification techniques available are reviewed below -

(a) recalibration of potentiometric measuring equipment

Equipment of this type consists essentially of a potentiometric indicator or recorder and may, in addition, incorporate a multi-term proportioning controller in one of a variety of forms. Such equipment, in one configuration or another, has been used extensively for the past twenty five years and forms the basis of many thousands of pyrometric installations in thermal treatment facilities throughout Australia.

Re-calibration of a potentiometric pyrometer for actuation by a different type of thermocouple (here, nicrosil versus nisil) is accomplished by changing a number of precision bridge resistors and whatever form of reference-junction device is involved*. For equipment of more recent origin (say, the past fifteen years), a complete 'range-change' facility often is available in one complete package which is generally called a 'plug-in range-card'. This card requires only to be appropriately plugged or screwed into the instrument, and often it does not even require further adjustment. A suitably graduated analogue scale, and matching chart (if for a recording device), completes the modification. Fig. 20 shows a typical arrangement.

Normally, this type of range-change facility is supplied by the manufacturer of the original equipment. The cost of modifying a serviceable potentiometric type instrument from, say, a type K to a nicrosil versus nisil thermocouple range should be, typically, $A(200 to 300).

(b) use of an external reference-junction temperature compensating device

If the manufacturer of some particular pyrometer has not developed a suitable reference-junction compensator, and range-change resistors, to permit proper re-calibration for nicrosil versus nisil, another approach is required. One alternative method is to use an external reference-junction device for nicrosil versus nisil which can be operated by either battery or mains power. Such units are normally held in stock in Australia. The nicrosil versus nisil thermocouple is connected directly to the external reference-junction device, if necessary via nicrosil versus nisil extension wire. The device electronically generates a voltage to modify the thermocouple output so that it equates to a reference-junction temperature of 0°C. Copper wires connect the reference-junction unit to the monitoring pyrometer, which is calibrated in a voltage span equivalent to the nicrosil versus nisil temperature range required. Hence, the monitoring instrument does not require any form of internal reference-junction temperature

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* The modification of the reference-junction compensation circuitry in a typical potentiometric pyrometer is described, in some detail, in Appendix VII.

compensation. The non-linear scale (and matching chart, if fitted) is manufactured to comply with the standard nicrosil versus nisil emf-temperature tables. A typical arrangement is shown in Fig. 21. The cost of a commercial reference-junction compensating device plus the cost of modifying a serviceable instrument should be, typically, $A(300 to 500).

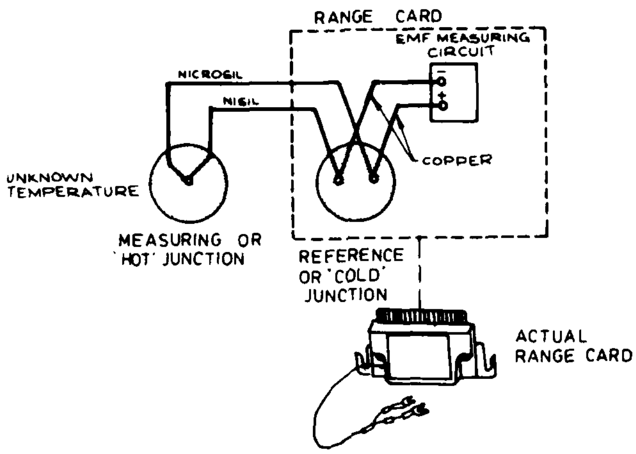

FIG. 20 'Plug-in range-card' facility for the recalibration of a potentiometric pyrometer for actuation by a different thermocouple.

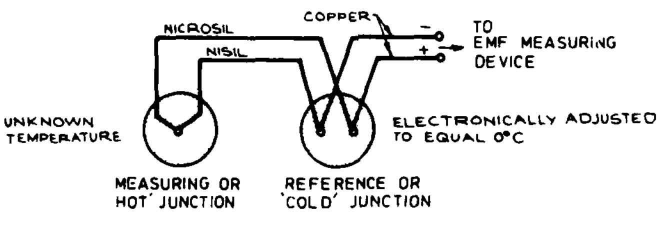

FIG. 21 Circuit arrangement for the use of an external reference-junction temperature compensating device.

(c) use of an external temperature transmitter

Another alternative is the use of an industrial temperature transmitter. Such devices are readily available in Australia, and several manufacturers stock (or can modify) units to operate with nicrosil versus nisil thermocouples.

Temperature transmitters are compact devices which operate, typically, from 240 V 50 Hz mains supply or 24 V DC supply. A temperature transmitter will be calibrated for a specific nicrosil versus nisil thermocouple range, include its own internal reference-junction compensation function, and provide an isolated 'high-level' output signal of, typically, (0 to 1) V or (4 to 20) mA. The mA signal can readily be converted to an appropriate voltage value by means of a precision shunt resistor.

The nicrosil versus nisil thermocouple is connected either directly or via extension leadwire to the temperature transmitter. Copper wires connect the transmitter to the monitoring instrument which, because of the high-level signal produced, can be distant from the transmitter by, say, up to one kilometre. The monitoring instrument will be calibrated to a specified voltage span equivalent to the output generated by the temperature transmitter. The non-linear scale (and chart, if fitted) will equate to the standard nicrosil versus nisil emf-temperature tables. A typical arrangement is shown in Fig. 22. The cost of a commercially available temperature transmitter, added to the cost of modifying a typical serviceable industrial instrument should be, typically, $A(500 to 700).

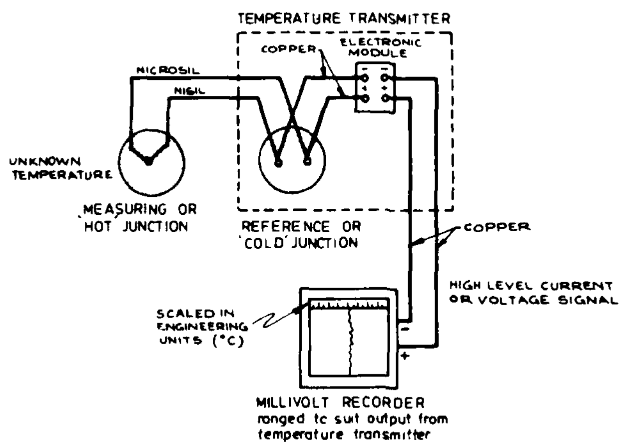

FIG. 22 Circuit arrangement for the use of a temperature transmitter in conjunction with a monitoring instrument.

5.4.3 *New instrumentation*

From a cost-effectiveness point of view, the most appropriate opportunity to introduce the nicrosil versus nisil thermocouple system into a process, plant or scientific project, is as part of a new installation. In this case, the whole operation can be appropriately planned, and the correct extension cabling (nicrosil versus nisil) installed. A similar opportunity will occur in an established plant which is being updated, say, to be more efficient and cost-competitive, or where the instrumentation itself, due to age, continuous usage or technology change, has become obsolescent or unsuitable. In an existing plant, the replacement of the thermocouple extension cabling may be a significant cost factor. Where a major plant update is undertaken, however, such a change is most likely unavoidable, and an economical introduction of the complete nicrosil versus nisil system is thus facilitated.

The recent introduction of microprocessor-based technology has significantly increased the flexibility and capability of most forms of industrial instrumentation. Many instrument supply companies have already incorporated a capability, in one form or another, of applying the nicrosil versus nisil thermocouple sensor to their own range of such equipment. This is accomplished in individual instruments by the use of plug-in type modules or bridging networks, by a variety of switch arrangements, or even by keyboard entry in more sophisticated devices. In most instances, instrumental functions will be executed using digital techniques, and thermocouple linearisation will be performed in software. Reference-junction compensation is, typically, carried out by measuring the thermocouple terminal temperature with a suitable sensor, and adding an equivalent value to the measured voltage from the thermocouple. The result is a direct readout of temperature, usually in digital form, corrected for ambient temperature variation. It is thus a relatively simple matter for the manufacturer to make provision, at the time of design, to include the nicrosil versus nisil thermocouple among other thermocouple types, or to add this new capability at some future time.

Most modern instruments and systems include an inherent capability for accepting nicrosil versus nisil thermocouples. When this is not the case, a potential user can exert pressure on an instrument supply company to have their overseas principals incorporate such a capability; alternatively, he can seek the services of another company that has already done so.

The types of new instrumentation and systems already characterised to accept nicrosil versus nisil thermocouples, and which are available from Australian sources, can be summarised as follows -

- Reference-Junction Devices
- Thermocouple-to-Current/Voltage Transmitters
- Direct-Reading Potentiometers and Test Equipment
- Analogue Indicators
- Digital Indicators
- Recorders (Continuous Record & Multi-Point Types)
- Controllers
- Data Logging Systems
- Distributed Process Control Systems
- Computer Based Systems

The cost of such equipment so characterised should, in most instances, be the same as that of equipment characterised for other thermocouple types.

5.4.4 Using a computer

A computer, be it a large centrally-based system or a low-cost desk-top unit, can provide the means to most effectively monitor nicrosil versus nisil thermocouples. The accuracy of the system will depend largely on the peripheral equipment selected for use with the computer, and this can vary from 'very high accuracy', as might be required in some demanding research program, to 'typical industrial accuracy'. Of great importance is the opportunity so afforded of processing the measured data, and here the possibilities are virtually limitless. Fig. 23 shows a typical arrangement, although there are many other possible arrangements.

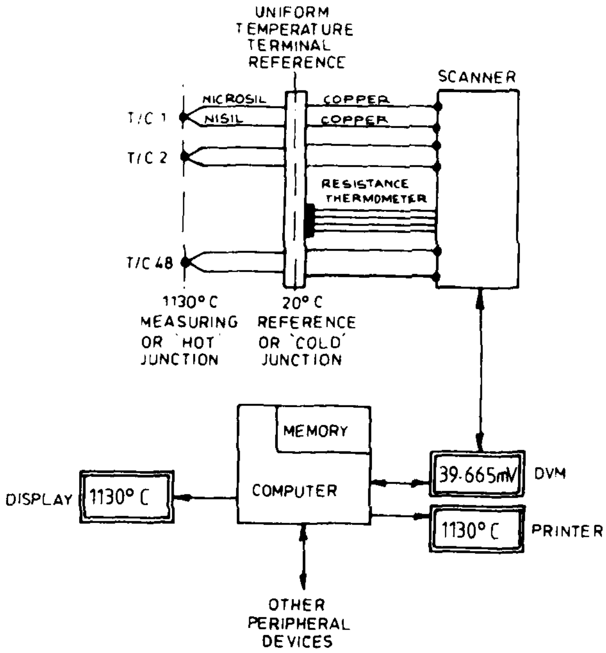

FIG. 23 A typical arrangement involving a computer to monitor nicrosil versus nisil thermocouples.

Fig. 23 shows how the nicrosil versus nisil thermocouples are connected to a uniform-temperature terminal reference device. If the thermocouples are remotely located, matching extension wires should be used. The reference device maintains all its terminals at a uniform temperature, but this temperature 'floats' by following the ambient temperature. These terminals are isolated from each other and ground. The temperature of the terminals is accurately measured, usually by a platinum resistance-thermometer. Copper wires connect the uniform-temperature terminal reference to an automatic scanning device, which is of a 'low-thermal-emf' design as it switches low-level thermocouple voltages. The scanning device puts out measured data to a suitable digital voltmeter, where it is converted to digital form and transferred directly to the computer. Suitable peripheral equipment, such as a direct-reading digital temperature indicator and a printer, will most likely be required. Manufacturers vend this type of equipment in a variety of forms, some being specifically packaged to accept thermocouples and like sensors.

In operation, an individual thermocouple voltage - proportional to the difference in temperature between the individual measuring-junction and the point where the thermocouple leads join the copper wires in the uniform-temperature terminal reference device (reference-junction) - is switched sequentially by the scanning device into the digital voltmeter. The measured voltage, together with appropriate thermocouple identification data, is transmitted in digital form to the computer and stored in memory. In the same sequence the signal from the resistance-thermometer mounted in the uniform-temperature reference device is likewise transmitted and stored in memory. The computer converts the thermometer resistance value to an equivalent voltage which it sequentially adds to the measured voltage of each thermocouple. The total value (representing the output voltage of each thermocouple referenced to 0°C) is converted to temperature by tabular look-up in an appropriate emf-temperature table for nicrosil versus nisil which has been stored in the computer memory. Alternatively, and increasingly likely, the nicrosil versus nisil thermocouple tables are developed in the computer using a power series expansion. A detailed description of the power series is given in NBS Monograph 161 [3].

5.5 *Summary*

It is obvious that would-be users of the nicrosil versus nisil thermocouple system can procure suitable sensors, extension wiring and monitoring instrumentation from Australian sources. In some instances, this may initially involve a little more expense; however, such transitory costs are minimal compared to the potential long-term economic benefits that this novel thermocouple system confers. Whatever these initial costs may be, they can only be regarded as an excellent investment in enhanced technology and increased productivity.

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13. C.D. Starr and T.P. Wang, *Effect of Oxidation on Stability of Thermocouples*, Proc. Am. Soc. Test. & Mater. 63, 1963, pp 1185-1194.

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APPENDIX I

Contributors:

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Reference: main text, section 4.2, page 11.

Title: CHEMICAL COMPOSITION AND THERMOELECTROMOTI FORCE OF TYPICAL COMMERCIAL MELT-BATCHES C NICROSIL AND NISIL

This appendix gives comparisons of chemical compositions and emf outputs of several alloy melt-batches of nicrosil and nisil alloys selected at random from recent commercial production of the major thern alloy manufacturers in the United States.

A1.1 Chemical Compositions

The chemical compositions of four such recent commercial allc batches each of nicrosil and nisil are given in Table 3. As is readil from the table all these batches, with the exception of two nicrosils w contain deliberately added magnesium, comply very closely with the nomi compositions specified in Reference 3. The magnesium-bearing nicrosil otherwise comply very closely with the specified compositions.

A1.2 Thermoelectromotive Force

Thermocouples of 8 AWG wires were fabricated in duplicate frc four melt batches of nicrosil and nisil referred to above. These thermocouples were calibrated at the National Measurement Laboratory (N Division of Applied Physics, CSIRO. The thermocouples were calibratec comparison with the Commonwealth Standards of Temperature Measurement. results, which are stated in terms of the differences between the therr emf's of the nicrosil versus nisil thermocouples and the corresponding of thermal emf given in the reference tables of Reference 3, are quotec Reports RS 11788 to RS 11795, inclusive, dated 20 May 1983.

The results of these calibrations are summarized graphically Fig. 24. No thermocouple deviated outside the limits specified for n: base alloy thermocouples by ASTM [11].

The data presented in this Appendix suggest that present-day commercial batches of nicrosil and nisil from the USA, are of very high quality in both chemical composition and thermoelectromotive force.

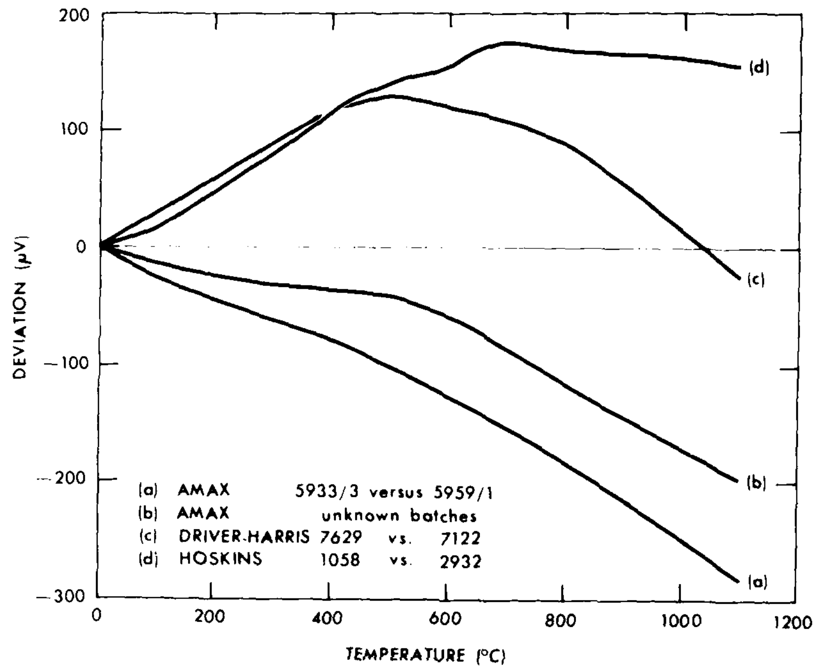

FIG. 24 Deviations of the thermal emfs of eight nicrosil versus nisil thermocouples fabricated from recent commercial melt-batches of each alloy. Each curve averages the deviations of duplicate thermocouples from corresponding emf values given in Reference 3.

TABLE 3 Comparisons of the compositions of four melt-batches each of nicrosil and nisil alloys of recent commercial production in the USA.

Alloy Identification		Chemical Composition[a]						
		Cr	Si	Mg	Fe	C	Mn	Zr
Specified								
Nicrosil	Comp.[b]	14.2	1.4	0.0	0.1	0.03	-	-
	Tol.	±0.15	±0.05	-	±0.03	max		
Nisil	Comp.	0.02	4.4	0.1	0.1	0.03	-	-
	Tol.	max	±0.2	±0.05	±0.03	max		
Driver-Harris								
Nicrosil	Comp.[c]	14.25	1.40	0.02	0.15	0.047	0.02	0.06
Melt No. 7629	Dev'n.[d]	-	-	+0.02	+0.02	+0.017	-	-
Nisil	Comp.	0.01	4.45	0.09	0.16	0.013	-	-
Melt No. 7122	Dev'n.	-	-	-	+0.03	-	-	-
Hoskins								
Nicrosil	Comp.	14.37	1.49	0.07[e]	0.06	0.039	-	-
Melt No. 1058	Dev'n.	+0.02	+0.04	+0.07	-0.01	+0.009	-	-
Nisil	Comp.	-	4.5	0.16	0.08	0.01	-	-
Melt No. 2932	Dev'n.	-	-	+0.01	-	-	-	-
Amax Specialty Metals								
Nicrosil	Comp.	14.35	1.44	0.07[e]	0.01	0.006	-	0.03
Melt No. 5933-3	Dev'n.	-	-	+0.07	-0.06	-	-	-
Nisil	Comp.	0.01	4.42	0.13	0.09	0.005	0.04	0.03
Melt No. 5959-1	Dev'n.	-	-	-	-	-	-	-
Amax Specialty Metals								
Nicrosil	Comp.	14.13	1.45	0.08[e]	0.10	0.005	-	-
Melt No.[f]	Dev'n.	-	-	+0.08	-	-	-	-
Nisil	Comp.	-	4.18	0.09	0.08	0.005	0.03	-
Melt No.[f]	Dev'n.	-	-0.02	-	-	-	-	-

(a) Percentage by weight; balance is nickel.
(b) Nominal compositional tolerances for nicrosil and nisil are as specified in Reference 3.
(c) The actual compositions quoted are based on analyses carried out at Materials Research Laboratories.
(d) All compositional deviations quoted are relative to the nominal compositional bounds specified in Reference 3.
(e) Although not specified in Reference 3, these alloys contain deliberately added magnesium.
(f) Melt number not known.

APPENDIX II

Contributor: J.W. Hobson
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Reference: main text, section 4.4.2, page 15, para. 3.

Title: EXAMPLES OF TRIALS OF NICROSIL/NISIL THERMOCOUPLES IN AUSTRALIAN GOVERNMENT DEFENCE PRODUCTION FACTORIES

A number of industrial trials of nicrosil versus nisil thermocouples have now been successfully completed in Government Defence Production Factories, Department of Defence Support, in Australia. It will be seen, from the following examples of trials involving different types of thermal-treatment installations, that in all cases nicrosil/nisil thermocouples showed significantly enhanced performance over conventional base-metal thermocouples.

A2.1 Box Furnace, No. 1 Forge Shop, Ordnance Factory, Maribyrnong, Victoria

As far as can be ascertained, this was the first industrial trial of the nicrosil/nisil thermocouple in Australia. It was carried out on behalf of the Joint Working Party referred to in section 4.4.2 of this report.

This trial featured an 8 AWG nicrosil/nisil thermocouple inserted into a specially made dual-compartment thermocouple sheath of Inconel 601. The second compartment contained a calibrated rare-metal reference thermocouple for comparison purposes. With the special sheath mounted in a usual recording position in the work-chamber, the box furnace was operated normally at a working temperature of 800°C.

After some 2000 h of intermittent operation at this working temperature, the relative calibration of the two thermocouples changed by less than 2°C. The detailed results of this trial are available in an MRL Report which is in course of publication.

A2.2 Continuous Brazing Furnace, Small Arms Factory, Lithgow, N.S.W.

This trial was of a nicrosil-nisil thermocouple of 15 AWG wires enclosed in a sheath of special design to overcome problems of furnace construction. The sheath featured a ceramic end-piece to eliminate inductive heating of an otherwise metallic section where it passed through the heating-element windings. An exothermic gas is usually directed into this furnace during the brazing process. The output of this thermocouple was compared to that of a calibrated rare-metal thermocouple, similarly mounted, while the furnace operated at 1100°C.

The results of this trial are summarized in Fig. 25, which shows that the difference in the temperatures indicated by the two thermocouples changed little up to 3500 h of operation.

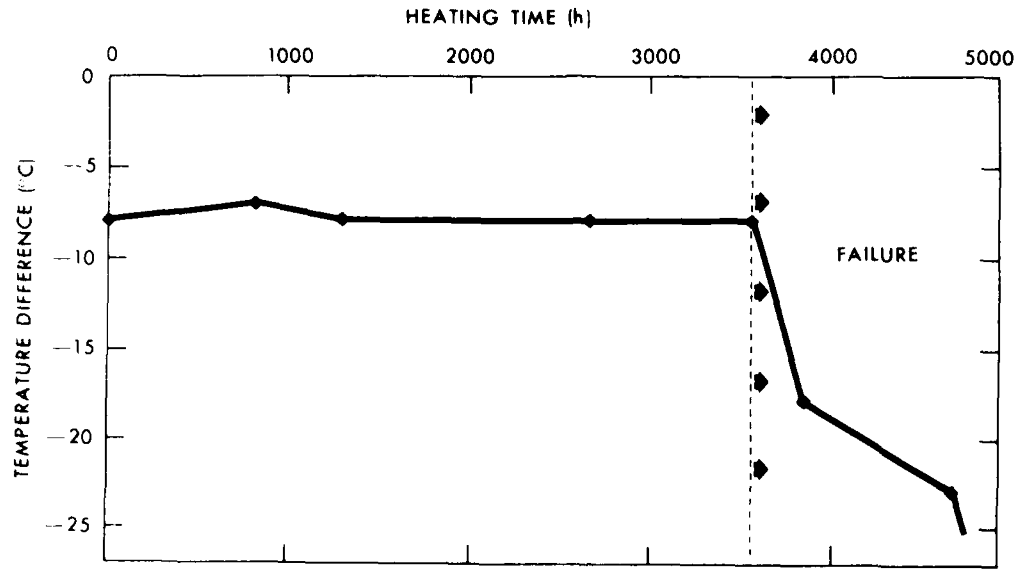

FIG. 25 Difference in indicated temperature between a 15 AWG nicrosil/nisil thermocouple and a calibrated rare-metal reference thermocouple installed in a continuous brazing furnace operating at 1100°C.

A2.3 Air-Circulation Furnace, Airframe Engineering Workshops, Pooraka, South Australia

This trial was mounted jointly by the Instrument Services Laboratory (SA) of the Department of Defence Support and the National Measurement Laboratory (SA Branch) of the CSIRO. Nicrosil/nisil thermocouples exposed to the moving air-stream at 700 to 950°C were monitored using calibrated checking thermocouples. After 250 h of operation no significant change in the temperatures indicated by the nicrosil/nisil thermocouples had occurred.

Opportunity was taken, during a recent workshop re-organization, to convert the pyrometric installations allied to all furnaces and salt baths operating at Pooraka to nicrosil/nisil actuation.

A2.4 Others

Although not a Commonwealth Government Department, it is of interest to note that the Grain Elevators Board of Victoria commissioned a trial of nicrosil/nisil thermocouples to be carried out by the Agricultural Engineering Section of the CSIRO, Dunolly, Victoria.

The process concerned aims to de-infest wheat entering silo storages by heating the air stream envelope through which it passes to temperatures below 100°C. The result of this trial has been a recommendation for the use of nicrosil/nisil thermocouples in this application in wheat storages throughout Australia.

APPENDIX III

Contributor: J.W. Hobson
Resources Division
Department of Defence Support

Reference: main text, section 4.4.2, page 16, para. 1.

Title: EXAMPLES OF TRIALS OF NICROSIL/NISIL THERMOCOUPLES IN THE PRIVATE SECTOR OF INDUSTRY IN AUSTRALIA

Following the trials in the Government Factories, exemplified in Appendix II, a number more have been carried out by various manufacturing firms in the private sector of industry in Australia. Two important examples of these trials, together with the results obtained, are described in this Appendix. Other trials are mentioned in passing. Once again, the enhanced performance of nicrosil versus nisil thermocouples is demonstrated.

A3.1 Chloride Salt Bath, Patience and Nicholson (McPhersons) Limited, Maryborough, Victoria

Several trials were conducted in chloride salt pots used for such heat-treatments as the hardening and tempering of high-speed steel tool pieces. These salt pots provide the most demanding of conditions for thermocouple sheaths, as corrosion processes at the molten salt/air interface can be very rapid.

The trial thermocouple featured a protection sheath designed for optimum salt exclusion. The sheath construction allowed for the insertion of an inner ceramic sheath in an outer metallic sheath of Inconel 600. The outer sheath was replaced, in accord with Patience and Nicholson normal practice, every 5 days or every 50 working hours whichever occurred the sooner.

The temperature indicated by the trial thermocouple, which was constructed of 9 AWG nicrosil and nisil wires, was compared to that indicated by a calibrated rare-metal test thermocouple when periodically inserted into the molten salt at 1220°C.

As can be seen from Fig. 26, the performance of the nicrosil/nisil thermocouple, continuously immersed in the molten salt, matched that of a rare-metal thermocouple for at least 250 h of operation, and behaved quite satisfactorily for this type of application for nearly 300 h. Since this period of time is about the maximum life of a rare-metal thermocouple normally used to indicate salt temperature during heat-treatment, it is clear that a nicrosil/nisil thermocouple could be used with considerable economic advantage in chloride wet baths.

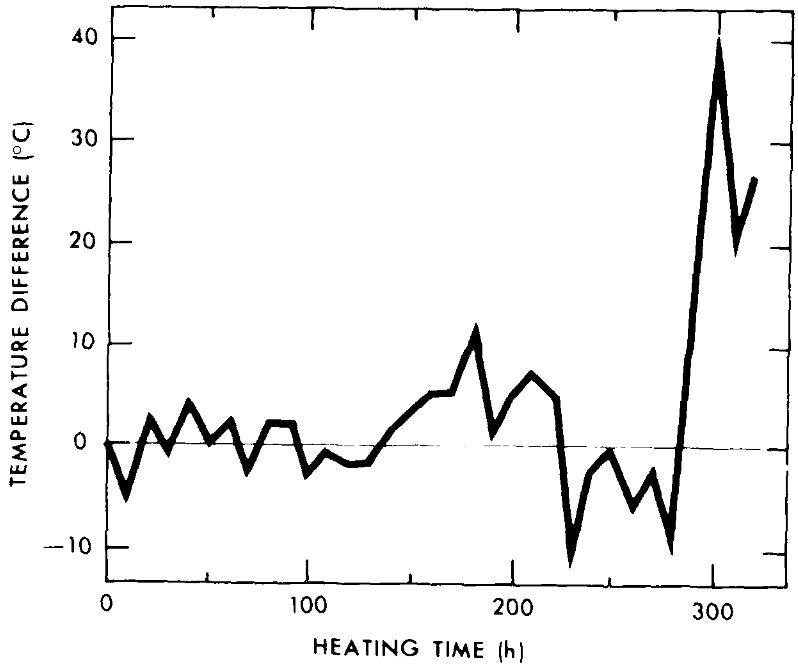

FIG. 26 Difference in indicated temperature between a 9 AWG nicrosil/nisil thermocouple installed in a molten chloride salt bath operating at 1220°C and a calibrated rare-metal reference thermocouple periodically inserted into the salt.

A3.2 Strip Annealing Furnace, Austral Bronze Crane Copper, Alexandria, N.S.W.

A trial nicrosil/nisil thermocouple installation in a bronze strip annealing furnace ran satisfactorily for 3000 h before arbitrary termination. The annealing furnace was a bell-type, and operated at 550°C with the thermocouple mounted vertically from below. In this installation the coils of strip (and the thermocouple assembly!) are water quenched at the conclusion of each annealing cycle. The overall accuracy of the pyrometric installation featuring the nicrosil/nisil thermocouple was checked periodically using calibrated checking thermocouples.

At the end of the test run, this accuracy was pronounced to be still thin the initial bounds specified, and the company has decided to convert the pyrometric installations allied to several such furnaces for nicrosil/nisil actuation.

A3.3 Others

Other trials of nicrosil/nisil thermocouples are in various stages of progress at Commonwealth Aircraft Corporation, Fishermens Bend, Victoria; Broken Hill Associated Smelters, Port Pirie, South Australia; and Comalco Aluminium, Bell Bay, Tasmania; to name but a few. Detailed results of these trials are not to hand.

APPENDIX IV

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Reference: main text, section 4.4.2, page 16, para. 2.

Title: EXAMPLES OF TRIALS OF NICROSIL/NISIL THERMOCOUPLES BY OVERSEAS AUTHORITIES IN SEVERAL COUNTRIES

Following on Appendices II and III, some salient examples are also given of trials carried out by various authorities in other countries which have culminated in the adoption of nicrosil/nisil thermocouples in important sectors of industry, including the manufacture of components for electronic computers and the generation of electricity by both conventional and nuclear means.

A4.1 Advanced Gas Cooled Reactor, UK Atomic Energy Authority, Windscale, UK

During a recent several-year run of this reactor, some experiments were performed to examine the behaviour of stainless-steel clad fuel pins under operational fault conditions when the temperature of the fuel pin cladding approached its melting point of ca. 1370°C.

Nicrosil/nisil thermocouples were used to measure the high temperatures of the coolant gas and fuel pin cladding encountered during the experiments. The thermocouple wires were swaged down to one mm diameter and annealed prior to use. The tests were of fairly short duration (minutes) but were carried out in an environment of CO_2 gas and an unspecified intensity of neutron irradiation. Secondary conclusions reached after these tests ended [15] were that no reason had arisen to doubt the calibration validity of the nicrosil/nisil thermocouples after 20 min duration of test, and that no effects were observed which would invalidate their subsequent use under such reactor conditions.

A4.2 Box Furnaces, General Products Division, International Business Machines, San Jose, California, USA

This is the first reported independent trial (1974) of nicrosil/nisil thermocouples overseas. The tests involved a large number of small box furnaces used for the critical cyclic heating of electronic components for computers up to a maximum temperature of 950°C. Using rare-metal reference standard thermocouples specially calibrated for the trials by the US National Bureau of Standards, direct comparisons of the thermoelectric stability of a number of 18 AWG thermocouples of type K and nicrosil/nisil were carried out during normal cyclic heating operations. The furnace temperatures were controlled and the outputs of the test thermocouples monitored by a digital control system based on an IBM 1130 computer.

The results of these tests were expressed using a concept called "thermal fatigue counts", the fatigue number, F, being given by the arbitrary equation

$$F = 0.0033 \sum_{i=0}^{N} \varepsilon^{T_i/433}$$

where T_i is in °C and N is the number of computer measurements above 200°C. F is computed every 20 seconds, when T_i > 200°C, and added to the previous value in an ongoing summation. Increments to the value of F are called "fatigue counts".

Results of these trials are summarised in Figs. 27 and 28.

The results show that all the nicrosil/nisil thermocouples deviated much less from their initial calibrations than did those of type K. Deviation to the point of failure first occurred at a fatigue number of 876 in a type K thermocouple. By the time a fatigue number of 1142 was reached, a total of five type K thermocouples had failed; by 1996 a total of eight type K units had failed and by 4070 the last type K unit failed. These failures were due to open-circuiting by through-oxidation.

No nicrosil/nisil thermocouples deviated to failure during the entire experiment.

A4.3 Bell-type Annealing Furnace (with Reducing Atmosphere), AMAX Specialty Metals Corporation, New Jersey, USA

Trial thermocouples of nicrosil/nisil wires were suspended vertically in a protection sheath, together with calibrated reference thermocouples, from the top of the bell-type furnace. The furnace was filled with a reducing gas, such as dissociated ammonia, and heated up to 1000°C.

Limited data [17] showed that nicrosil/nisil thermocouples were stable at this temperature in the reducing atmosphere; the change in calibration of 8 AWG thermocouples was less than 5°C after 14,400 h (20 months) of heating.

It is to be noted that type K thermocouples are not recommended [11] for service in reducing atmospheres at an elevated temperature.

It is further reported [17] that other plant tests using 14 AWG and 8 AWG nicrosil/nisil thermocouples showed changes in calibration of less than 6°C for exposures from 150 h up to seven months for three different atmospheres, dissociated ammonia, ($90N_2 + 8NH_3$), CH_4, CO, and N_2, at temperatures in the range 870 to 1120°C.

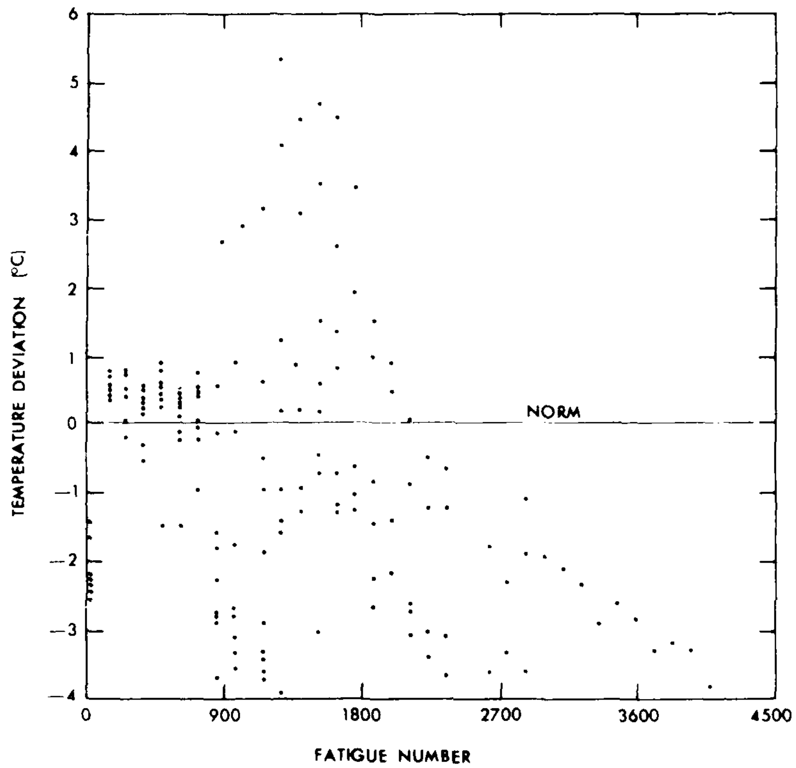

FIG. 27 Deviations of the temperatures indicated by the various IBM type K trial thermocouples from the 'norm' temperatures being that equivalent to 30 mV (reference 4).

Note each vertical column of dots relates to the fatigue number (see text) at the end of an individual thermal cycle of furnace operation (from reference 16).

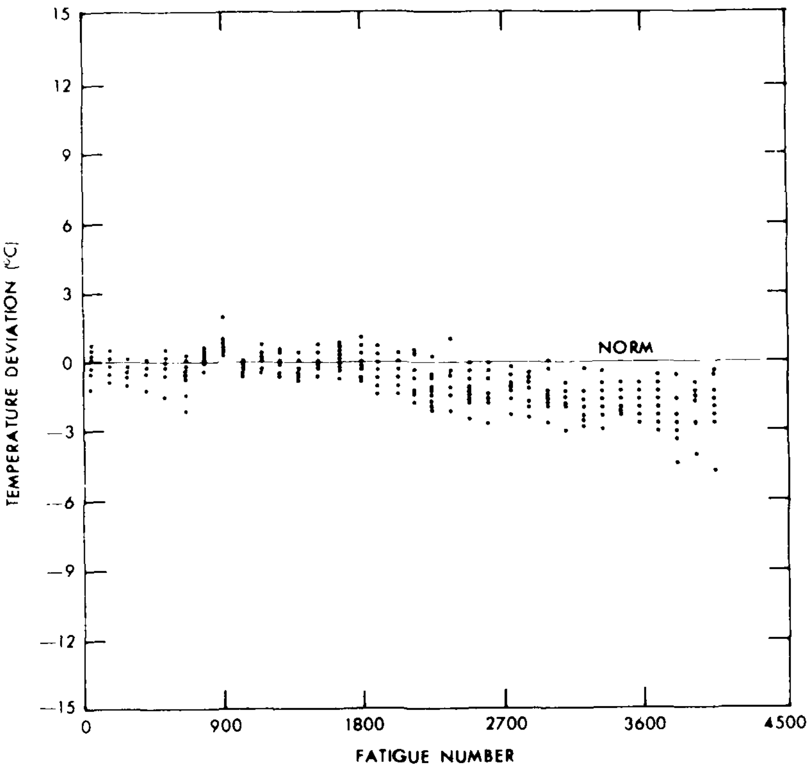

FIG. 28 Deviations of the temperatures indicated by the various IBM nicrosil/nisil thermocouples from the 'norm' temperature being that equivalent to 30 mV (reference 3). See note in caption to Fig. 27 (from reference 16).

A4.4 Steam Boiler, EBASCO Group, New York, N.Y.

The EBASCO Group of power engineering consultants, under contract to the State Energy Authority of New South Wales, is using the No.2 steam boiler at the Liddell Power Station in the Hunter Valley to study the calorific properties of various indigenous coals used to fuel the Authority's boilers. EBASCO turned to nicrosil/nisil thermocouples in this application because type K thermocouples had shown inadequate thermoelectric stability.

The Liddell No.2 trial-installation comprised some 420 nicrosil/nisil thermocouples of the mineral-insulated integrally-sheathed variety located to measure flue gas, steam and boiler tube temperatures in the range 400 to 1300°C. These thermocouples, which were manufactured in the USA, put their signals out to a digital voltmeter/scanner monitoring system under computer control.

EBASCO has found the performance of the nicrosil/nisil thermocouples to be most satisfactory in this demanding application, and intends to use them in all future tests of this kind.

A4.5 Industrial Tube Furnace, SODERN, Paris, France

The tests summarized [18] were effected using 2 mm OD mineral-insulated integrally-sheathed (inconel) thermocouples of both type K and nicrosil/nisil. These thermocouples were heated at temperatures up to 1150°C in air in a stainless steel thermal stabilizing block positioned in an 'Adamel' industrial tube furnace.

The thermal emf drifts of the nicrosil/nisil and type K thermocouples were determined by reference to a calibrated rare-metal thermocouple introduced episodically into the thermal stabilizing block. The results of these tests are given in Table 4, from which the marked superior thermoelectric stability of nicrosil/nisil is evident.

In separate tests, the effects of cold-working the thermocouples were assessed. This was done by comparing the thermal emfs of cold-worked thermocouples, which had been wound around an 80 mm diameter mandrel and straightened, with the emfs of annealed thermocouples. The SODERN report [18] claims that the change in thermal emf induced by the cold-working described is five times greater for type K than for nicrosil/nisil.

TABLE 4 Comparisons of the thermal emf drifts of the SODERN trial thermocouples at various temperatures in air.

Thermocouple Type	Temperature (°C)	Time (h)	Drift (μV)
K	600	2400	+20
N	600	2400	-7
K	900	2400	-45 to -73
N	900	2400	+45 to +85
K	1020	2700	-271 to +442
N	1020	2700	-46 to +50
K	1150	336	-130 to -341
N	1150	336	+36 to +37

APPENDIX V

Contributor: J.A. Coleman
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Reference: main text, section 5.2.3, page 19

Title: NOTES ON THE WELDING OF NICROSIL TO NISIL TO FORM THERMOJUNCTIONS

A5.1 General

Because of the similarity of appearance of nicrosil and nisil, care should be taken to identify the wires as they are being cut prior to welding. The wires should be cut about 50 mm over-length to allow remaking of faulty welds, should this be necessary.

After cutting, the wires should be degreased with a suitable solvent (e.g. shellite) and the 40-50 mm at the ends to be welded should be further cleaned using fine abrasive paper (320-400 grade). The junction should now be formed by twisting the cleaned ends of the wires together for one and one half complete turns. The twisted section should occupy a length of about 15-20 mm.

A5.2 Setting of Flame for Oxy-Acetylene Welding

A neutral flame is essential; any variation should be towards a slightly reducing flame. For 8 AWG (3.25 mm) wires, a No. 2 tip for a Comweld welding blow-pipe is an appropriate tip size with about 70 kPa (10 psi) set on both the oxygen and acetylene regulators.

Overheating should be avoided, and the weld should be completed as quickly as possible. The welder should not try to run the bead over more than about half a twist (approx 6 mm). He should not reweld a welded junction to correct a faulty weld; the faulty junction should be cut off, the wires cleaned and re-twisted, and a new weld made.

A5.3 Flux

Fluxes containing borates should not be used under any circumstances. These may cause hot cracking in the weld metal. An active fluoride-bearing flux, of the type suitable for inconel, is effective.

Complete removal of the flux after welding is essential as any residual flux may react with the thermocouple alloys at high service temperatures. A motor-driven rotary wire brush is probably the best means of removing the flux. Chemical cleaning procedures should not be used, as chemical residues may also attack the wires at elevated service temperatures.

If argon-arc welding facilities (TIG) are available this method is to be preferred, as the junction may be welded without the use of flux. A welding current of about ten amperes is a good starting point. A shroud to assist in maintaining a good inert gas envelope around the weld zone is desirable.

APPENDIX VI

Contributor: R.M. Hess
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Reference: main text, section 5.4.1, page 23, para. 1.

Title: ANALYSIS OF ERRORS INTRODUCED BY THE USE OF CONVENTIONAL (ANSI TYPES J, K, R, S, or T) LEADWIRES WITH NICROSIL/NISIL THERMOCOUPLES

Occasions may arise when it becomes expedient to install a nicrosil/nisil thermocouple and its associated pyrometer, without replacing the pre-existing extension or compensating leadwire cabling. This leadwire originally may have matched an ANSI thermocouple type J, K, R, S or T and, as such, is not matched in calibration to nicrosil/nisil.

The question then arises as to the magnitude and sign of any temperature measurement error introduced by this mis-match. What follows is an analysis of the thermocouple circuitry showing how the error signal is produced. Signal magnitudes are then quantified for each of the above ANSI thermocouple types and are summarised in graphical form to illustrate the relationship of 'Error Magnitude' to 'Temperature Difference between Leadwire Terminations'.

The symbols used in the analysis have the following meanings-

E	:	thermoelectromotive force (thermal emf)	(μV)	) may have
D	:	difference in thermal emf's, or error signal	(μV)	) subscripts or be
S	:	Seebeck coefficient	(μV/°C)	) used as
T	:	temperature	(°C)	) subscripts
A	:	subscript denoting an ANSI type thermocouple		
N	:	subscript a denoting nicrosil/nisil thermocouple		

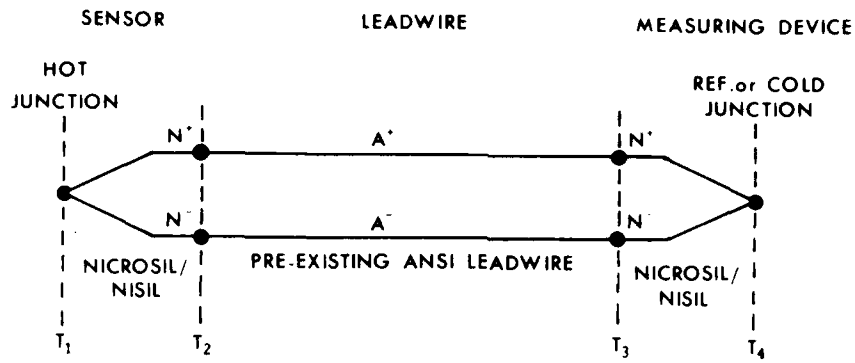

FIG. 29 Schematic thermocouple circuit used to illustrate the errors induced by the use of mis-matched thermocouple leadwire.

Referring to Fig. 29, it is evident that for an ideal nicrosil/nisil thermocouple, with nicrosil/nisil leadwire, the thermal emf, E total, would be given by -

$$E_N(\text{total}) = [E_N(T_1)-E_N(T_2)] + [E_N(T_2)-E_N(T_3)] + [E_N(T_3)-E_N(T_4)]\ \mu V \quad ...(1)$$

which, for a $T_4 = 0°C$, would equal the tabular value of the corresponding thermal emf given for T_1 in Reference 3.

However, with a mis-matched ANSI type leadwire present the thermal emf would be different, as given by -

$$E_N(\text{total}) = [E_N(T_1)-E_N(T_2)] + [E_A(T_2)-E_A(T_3)] + [E_N(T_3)-E_N(T_4)]\ \mu V \quad ...(2)$$

where the change is in the middle term. This change can be written as

$$D = [E_A(T_2)-E_A(T_3)] - [E_N(T_2)-E_N(T_3)]\ \mu V \quad ...(3)$$

For the relatively small temperature differences which normally obtain in practice (< 100°C), these functions can be expressed in terms of the Seebeck coefficients for the relevant thermocouple types as

$$D = S_A(T_2-T_3) - S_N(T_2-T_3)\ \ \mu V$$

which simplifies to

$$D = (S_A - S_N)(T_2 - T_3) \quad \mu V \qquad \ldots(4)$$

and can be written as

$$D = S_D\ (T_2 - T_3) \quad \mu V$$

where $S_D = (S_A - S_N)$.

Thus far D is expressed as a thermal emf whose magnitude is a function of the temperature difference between the two ends of the original mis-matched leadwire.

To convert D into an equivalent temperature error it must be divided by the Seebeck coefficient of the nicrosil/nisil thermocouple at the operating temperature, i.e. $S_N(T_1)$.

$$T_{err} = D/S_N(T_1) = S_D(T_2 - T_3)/S_N(T_1) \ {}^{\circ}C \qquad \ldots(5)$$

Putting actual values to the above terms we find that -

(i) In the normal ambient temperature range (T_2-T_3) centered around, say, 25°C $S_N = 26.8\ \mu V/^0C$ for nicrosil/nisil, while for the ANSI type thermocouples

A = type K	S_K	= $40.5\ \mu V/^0C$
A = type J	S_J	= $51.7\ \mu V/^0C$
A = type T	S_T	= $40.7\ \mu V/^0C$
A = type R or S	S_R (or S_S)	= $5.9\ \mu V/^0C$

(ii) In the range 1000°C to 1230°C S_N varies from 38.6 to 36.7 $\mu V/^0C$, so that an effective mean value of $S_N(T_1)$ would be 38 $\mu V/^0C$.

(iii) This gives T_{err} values as follows -

$T_{err}(K)$ = 0.36°C/°C
$T_{err}(J)$ = 0.66°C/°C
$T_{err}(T)$ = 0.37°C/°C
$T_{err}(R \text{ or } S)$ = -0.55°C/°C

The graphical representations of these error values in Fig. 30 shows T_{err} as a function of the temperature difference between the ends of the original mis-matched leadwire.

From the foregoing it is evident that, if the need arises to employ a mis-matched leadwire system, it is most desirable to keep the temperature difference between the opposite ends of the leadwire small, and to minimise any fluctuations in this temperature difference.

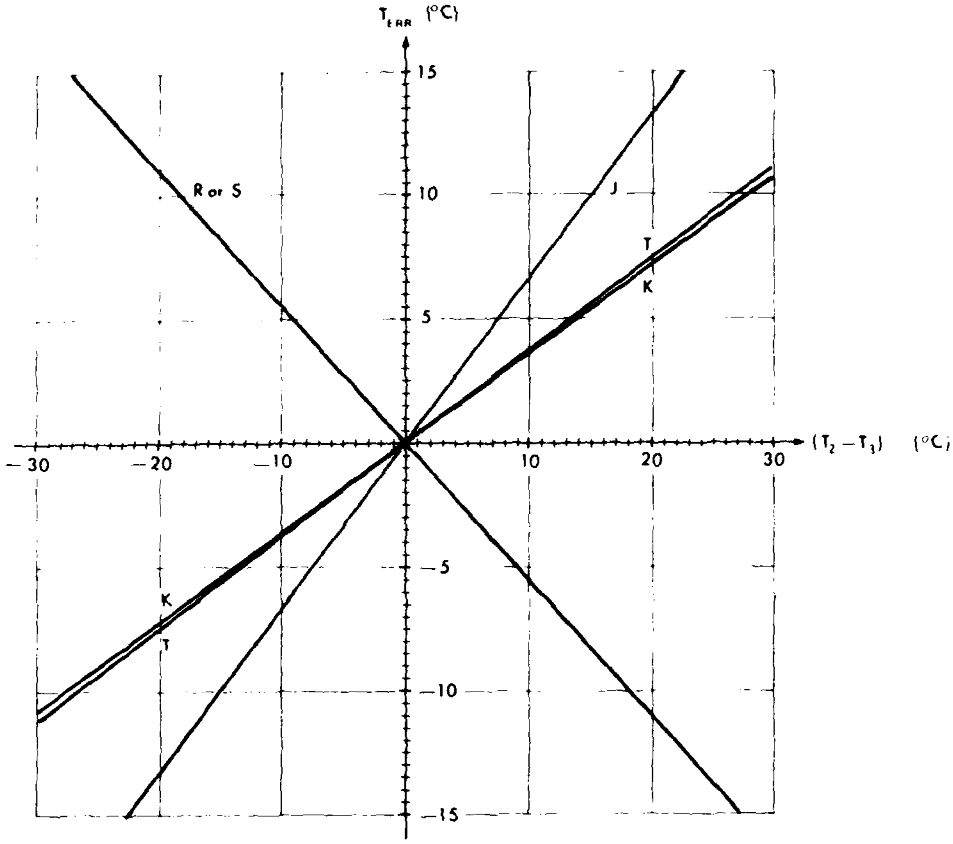

FIG. 30 Relationships between the 'Temperature Errors', T_{err}, and the temperature differences between leadwire ends, (T_2-T_3), for various ANSI type leadwires, when used with nicrosil/nisil thermocouples.

APPENDIX VII

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Reference: main text, section 5.4.2(a), footnote to page 24.

Title: MATCHING OF PYROMETER REFERENCE JUNCTIONS TO NICROSIL/NISIL THERMOCOUPLES

A7.1 An essential step in moving a new type of thermocouple out of the laboratory and into general usage is the provision of instrumentation compatible with, and calibrated for, the newcomer. An obvious requirement is that the scaling of the instrument must have the same thermal emf-temperature characteristics as the new thermocouple. Less obvious, but equally necessary, is the provision of reference-junction compensation to simulate a constant cold-junction temperature. To simplify the calculation of measuring-circuit constants the simulated temperature is usually put at 0°C. Modern thermoelectric pyrometers have their reference-junction compensation provided either by a temperature-stabilised enclosure (e.g. a peltier ice-point chamber, oven or equalizing block) or by a compensating network incorporated in the measuring circuit.

A7.2 This appendix is confined to a description of the three main types of compensating network used in pyrometer measuring circuits and to the means and calculations involved in modifying them to match a new thermocouple.

The compensating network uses one of three methods described below to sense variations in ambient temperature and to generate the appropriate correction voltage. The classical method is to sense the change in ambient temperature with a low-value wire-wound resistor of known positive temperature coefficient. A constant current of appropriate value is passed through the resistor to generate the correction voltage.

A second method of compensation is to sense the change in ambient temperature with a thermistor having a high resistance and a large negative temperature coefficient. The resulting resistance change causes a proportional change in the current flowing through the thermistor. This current also flows through a fixed resistor of appropriate value to generate the correction voltage.

Finally, compensation can be achieved by sensing the ambient temperature with a forward-biased silicon diode which has a negative coefficient of potential drop (typically -2 mV/°C). In this case the correction voltage is generated by a fixed-value resistance divider connected in parallel with the diode.

Irrespective of the type of compensation network used, the calculations involved in modifying the network values to provide correct compensation are quite straightforward. The methods used to convert the three types of reference-junction compensation circuit for a new thermocouple are described below, and an example is given for each type.

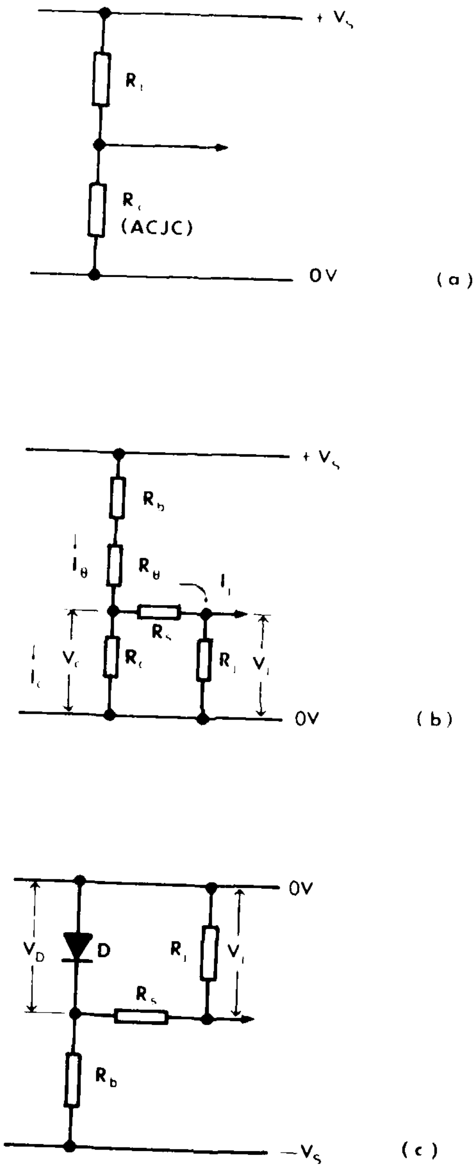

FIG. 31 Circuits of typical reference-junction compensating networks

(a) wire-wound resistor - positive temperature coefficient of resistance
(b) thermistor - negative temperature coefficient of resistance
(c) diode - negative temperature coefficient of voltage

A7.3 Wire-wound positive temperature coefficient resistor

The change in the thermal emf of the thermocouple, due to the change in reference-junction temperature, is compensated for by an opposing change of equal magnitude in the potential drop across the 'automatic cold-junction compensation' (ACJC) resistor (Fig. 31(a)) incorporated in the potentiometric bridge measuring circuit. Due to the presence of fixed large-value resistors in the bridge arm, the overall change in bridge arm resistance is so small that there is no significant change in the magnitude of the bridge arm current.

This can be expressed as follows-

Let S be the average Seebeck coefficient of the thermocouple over the operating range of ambient temperature for the instrument.

As the ambient temperature rises the emf output of the thermocouple decreases at a rate of S $\mu V/^0C$. Hence the ACJC coil must compensate by increasing the potential drop across it at a rate of S $\mu V/^0C$. The ACJC coil has a constant current i mA flowing through it, so that its resistance must increase at a rate of

$$\delta r = S/i \ m\Omega/^0C \qquad \ldots 1$$

Over the range of ambient temperature $(T_2 - T_1)$ °C

$$\delta r = (R_{T_2} - R_{T_1}) \ / \ (T_2 - T_1) \ m\Omega/^0C \qquad \ldots 2$$

where R_T is the resistance of the ACJC coil at temperature T. Hence the compensating coil needs to be made of a material having a temperature coefficient of resistance α, where -

$$\alpha = \left(\frac{R_T - R_O}{R_O}\right) \cdot 1/T \qquad \ldots 3$$

R_O being the resistance of the coil at 0°C.

The ACJC coil is wound in either copper or nickel for the temperature-sensitive part, and ballasted up to the required total resistance value with manganin or a similar alloy having a temperature coefficient of resistance of zero.

The temperature coefficients of resistance of copper and nickel vary depending on purity and condition, but are usually considered to be approximately -

$$\alpha_{Cu} = .004 \ \Omega/\Omega/^0C = 4 \ m\Omega/\Omega/^0C$$

$$\alpha_{Ni} = .006\ \Omega/\Omega/^0C = 6\ m\Omega/\Omega/^0C$$

The amount of temperature-sensitive wire required for the ACJC coil can simply be calculated, from Eqs. 1,2 and 3, as -

$$r_o = \delta r/\alpha \qquad \ldots 4$$

where r_o is the value of the resistance of the temperature sensitive wire in ohm at 0°C. As it is inconvenient to wind and measure the temperature-sensitive resistance at 0°C, the resistance value at a convenient temperature T is calculated by

$$r_T = r_o\ (1 + \alpha T) \qquad \ldots 5$$

This value should be measured and adjusted after the coil has been wound and thermally aged to relieve residual internal stresses. The coil is then made up to the value R_T by ballasting with manganin or similar alloy and adjusting after ageing.

Example: To calibrate a Leeds & Northrup 'Speedomax' instrument to operate with nicrosil/nisil thermocouples, the ACJC coil is to be $R_{40.5} = 6.100\ \Omega$: i = 5 mA : S = 26.8 μV/°C : coil-winding temperature to be 25°C: $\alpha_{Ni} = 5.7\ m\Omega/\Omega/^0C$.

(i) $\delta r = {}^{26.8}/5 = 5.36\ m\Omega/^0C$ (cf Eq. 1)

(ii) $r_o = {}^{5.36}/5.7 = 0.9404\ \Omega\ @\ 0^0C$ (cf Eq. 4)

(iii) $r_{25} = 0.9404\ (1 + 0.0057 \times 25) = 1.0744\ \Omega\ @\ 25^0C$ (cf Eq. 5)

(iv) $R_{25} = R_{40.5} - \delta r(40.5 - 25) = 6.100 - 0.00536 \times 15.5$

$= 6.100 - 0.0831 = 6.0169\ \Omega$

(v) Manganin required (not temperature-dependant) is $R_{25} - r_{25}$

$6.0169 - 1.0744 = 4.9425\ \Omega$

A7.4 Thermistor negative temperature coefficient resistor

In this type of circuit, shown in Fig. 31(b), the temperature sensing resistor experiences quite a large change in resistance so that the bridge arm current is not constant. Hence the change in thermocouple output is compensated for by an opposing change of equal magnitude in the potential drop generated across a fixed resistor.

This can be expressed as follows-

If S is the average Seebeck coefficient of the thermocouple operating range of ambient temperature for the instrument, the output thermocouple will change by S $\mu V/^0C$. Hence the resistance of the ACJ thermistor must change to vary the current I mA flowing through it so alter the potential drop across the ACJC resistor R_j at the compensati of S $\mu V/^0C$.

It is necessary to know the temperature-resistance character of the specific type of thermistor used. This can be obtained from t manufacturer's data, or it may be measured over the range of ambient temperature for which compensation is required. It is also desirable define the values of some of the network components shown in Fig. 31(b terms of standard-value resistors. In Eurotherm precision controller instance, $R_s = 1500\ \Omega$, $R_j = 10\ \Omega$; and $R_b = 8200\ \Omega$. This means that o needs to be calculated and adjusted to provide the required compensati follows. The thermistor R_θ at 25°C has a resistance of 1500 Ω (± 20% has a B factor of 3550 Ω (± 5%). Hence its value at any other temper can be calculated, using the equation

$$R_T = R_{25} \left(\frac{B}{T + 273} - \frac{B}{25 + 273}\right)$$

This temperature-resistance characteristic is presented graphically in Fig. 32. As the network supply voltage is stabilised at 9 V, the corresponding temperature - network current I_θ relationship can be cal by

$$I_\theta + 9/(R_\theta + R_b + R_c^1)$$

where $R_c^1 = R_s/R_c(R_s + R_j)$

where $R_s = R_j + R_c$

and never exceeds 1000 Ω, irrespective of thermocouple type. The temperature-current characteristic is presented graphically in Fig. 33 the normal range of ambient temperatures for which these instruments o 10 to 50°C, the average rate of change of current, δI, is 9.7 $\mu A/^0C$. required change in emf, $\delta V_j\ /\ ^0C$ across resistor R_j is 26.8 μV, the corresponding rate of change of emf, δV_c across R_c is

$$26.8 \times \frac{R_s + R_j}{R_j} = 26.8 \times \frac{1500 + 10}{10} = 26.8 \times 151 = 4.047\ mV/^0C.$$

$$\text{Hence } R_c^1 = \delta V_c/I = 4.047 \times 10^{-3}/9.7 \times 10^{-6} = 417.$$

$$\text{Since } R_c = 1/(1/R_c^1 - 1/(R_s + R_j))$$

$$R_c = 1/(1/405 - 1/1510) = 576\ \Omega.$$

Considering the spread of tolerances on circuit components, particularly the thermistor, the fitting of a 560 Ω (±2%) resistor for R_c will give satisfactory compensation for normal industrial applications.

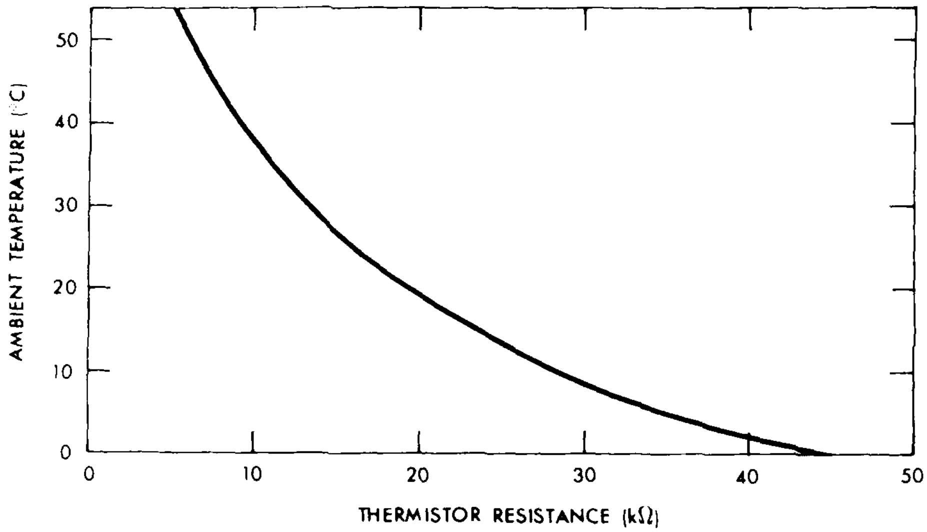

FIG. 32 Temperature/resistance characteristic of typical thermistor

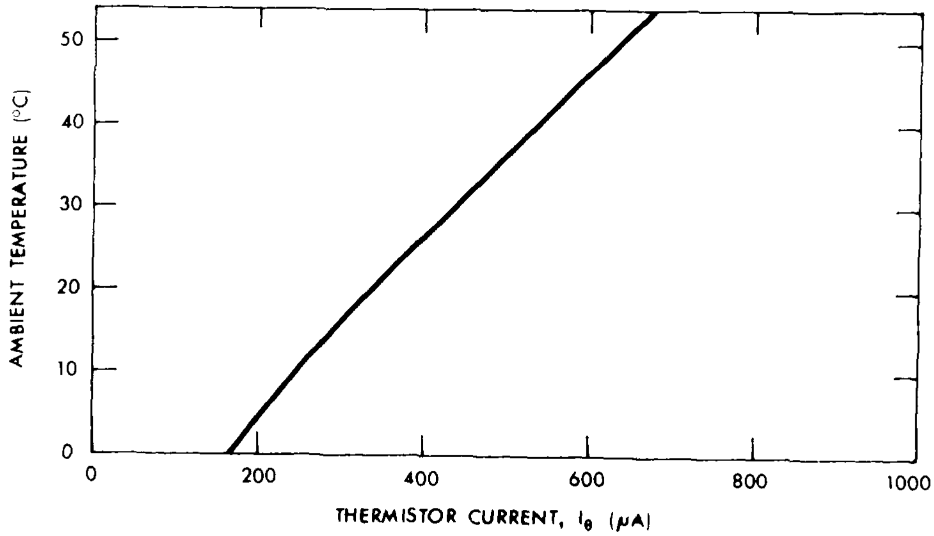

FIG. 33 Temperature/current characteristic of compensating network for a particular thermistor.

A7.5 Silicon diode

In this type of circuit, shown in Fig. 31(c), the temperature sensing diode has a forward bias current of just over 1 mA. The voltage drop across the diode is about 0.6 V at room temperature and typically it has a temperature coefficient of voltage (ΔV) around -2 mV/°C (± 25%). This temperature coefficient of voltage is characteristic, to fairly close limits (± 5%), for a given type and make of diode and is essentially linear in the temperature range -50°C to ±150°C. Hence the potential drop across the diode can be impressed across a voltage divider circuit ($R_s + R_j$) having a ratio which will produce the required compensation rate S µV/°C across R_j. Due to other circuit considerations, R_j must be usually kept low in value so that the ratio of R_s to R_j may be expressed as

$$R_s : R_j = (\Delta V - S) : S$$

$$R_s = \left(\frac{\Delta V - S}{S}\right) R_j$$

This diode compensation circuitry is used in Ether 'Digi' controllers, amongst others. For this model of instrument the circuit constants are as follows

$$R_b = 5600\ \Omega,\ \Delta V_D = -2.08\ \text{mV}/^0\text{C nominal,}$$

$$R_j \text{ not to exceed } 22\ \Omega.$$

To modify the compensation for nicrosil/nisil thermocouples, $S = 26.8\ \mu V/^0C$

$$R_s = \left(\frac{2080 - 26.8}{26.8}\right) R_j$$

$$= 76.6\ R_j$$

Hence for $R_j = 12\ \Omega$, $Rs = 12 \times 76.6 = 919\ \Omega$

Again, considering the spread of tolerances on circuit components, the fitting of $R_j = 12\ \Omega$ and $R_s = 910\ \Omega$ 2% resistors will give satisfactory compensation for normal industrial applications.

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